THE RELATIONSHIP BETWEEN REPETITION PRIMING AND SKILL ACQUISITION

Dan J. Woltz

University of Utah

January, 1993

Final Report

Contract AFOSR-91-0238

Air Force Office of Scientific Research
Life Sciences Directorate
Bolling AFB DC 20332-6448

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION: University of Utah / 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION: AFOSR/NL
6c. ADDRESS (City, State, and ZIP Code): 327 Milton Bennion Hall, Salt Lake City, Utah 84112	7b. ADDRESS (City, State, and ZIP Code): 110 Duncan Ave, Suite B115, Bolling AFB, DC 20332-0001
8a. NAME OF FUNDING/SPONSORING ORGANIZATION: AFOSR / 8b. OFFICE SYMBOL (If applicable): NL	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: AFOSR-91-0238
8c. ADDRESS (City, State, and ZIP Code): Bolling AFB, DC 20332-6448	10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. 61102F; PROJECT NO. 2313; TASK NO. A7; WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)

The Relationship Between Repetition Priming and Skill Acquisition

12. PERSONAL AUTHOR(S) Woltz, Dan J.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM June 91 TO Nov 92	Jan. 93	59

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	cognition; individual differences; memory; implicit memory; skill acquisition; learning

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This research investigated the existence and generalizability of individual differences in the implicit memory phenomena of repetition priming (i.e., performance facilitation on repeated cognitive processing events that does not depend on conscious recollection of the relevant prior events). In particular, the research estimated the relationship between individual differences in repetition priming and differences in cognitive skill acquisition. Three hundred and five Air Force enlisted personnel performed nine computerized cognitive tasks designed to measure repetition priming, event recognition (an explicit memory measure), and skill acquisition in the verbal, quantitative, and spatial processing domains. Individual differences in repetition priming were consistent across differing trial contents within each processing domain. These differences generalized across processing domains to a lesser extent. Contrary to expectations from current theory, priming and event recognition were correlated, especially within processing domain. Finally, consistent with the notion that repetition priming and skill acquisition reflect shared memory mechanisms, individual differences in priming uniquely predicted differences in skill acquisition.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION
22a. NAME OF RESPONSIBLE INDIVIDUAL: Dr John F. Tangney	22b. TELEPHONE (Include Area Code): (202) 767-4278 AFOSR/NL / 22c. OFFICE SYMBOL: NL

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted
All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

1993

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SUMMARY

This research investigated the existence and generalizability of individual differences in the implicit memory phenomena of repetition priming (i.e., performance facilitation on repeated cognitive processing events that does not depend on conscious recollection of the relevant prior events). Specifically, the research looked at (a) the reliability of individual differences in repetition priming within and across verbal, quantitative, and spatial processing domains, (b) the relationship between differences in repetition priming and differences in the ability to consciously recollect the processing events responsible for the performance facilitation (explicit memory), and (c) the relationship between differences in repetition priming and differences in skill acquisition.

Three hundred and five Air Force enlisted personnel performed nine computerized cognitive tasks designed to measure repetition priming, event recognition, and skill acquisition in the verbal, quantitative, and spatial processing domains. In contrast to most implicit memory research which utilizes data-driven tasks (i.e., facilitation depends on perceptual memories), the current measures of repetition priming were assumed to be primarily conceptually-driven (i.e., facilitation depends primarily on memory for conceptual/semantic processes).

Individual differences in repetition priming were consistent across differing trial contents within each processing domain. These differences generalized across processing domains to a lesser extent. Differences in the measures of event recognition and skill acquisition were also internally consistent and reflected a similar degree of processing domain specificity. The existence of reliable individual differences in the priming measures was contrary to several current theoretical perspectives on implicit cognitive phenomena. Also contrary to expectations from current theory, individual differences in priming were not independent of differences in event recognition. Measures of the two constructs were correlated, especially within processing domain. Finally, consistent with the notion that repetition priming and skill acquisition reflect shared memory mechanisms, individual differences in priming uniquely predicted differences in skill acquisition. This relationship also reflected a degree of processing domain specificity.

The apparent contradictions of the current research findings with existing theoretical perspectives on implicit and explicit memory measures might be due to the conceptually-driven nature of experimental tasks used. This underscores the need for future implicit memory research to employ measures tapping a wider variety of cognitive processes (i.e., not just data-driven tasks). With respect to theory on cognitive ability differences, the evidence suggests that individual differences in later stages of skill acquisition, which historically have been difficult to explain and predict, may reflect differences in the functioning of implicit memory mechanisms.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

The research described in this report was conducted with the cooperation of the Learning Abilities Measurement Program (LAMP), a multi-year basic research project of the Air Force Armstrong Laboratory which is partially sponsored by the Air Force Office of Scientific Research. I wish to thank Patrick Kyllonen, William Tirre, Valerie Shute, Scott Chaiken, and Raymond Christal for their assistance and suggestions during the conduct of this research. I am also greatly indebted to Cindy Garcia, Rich Walker and other member of the OAO Corporation for their programming efforts.

INTRODUCTION

Repetition priming, or the performance facilitation observed on a single repetition of a processing event, has been investigated using a variety of cognitive tasks. Substantial and persistent facilitation has been observed for repeated (or directly primed) trials in a variety of verbal processing tasks including word identification (Feustel, Shiffrin, & Salasoo, 1983; Jacoby, 1983, Jacoby & Dallas, 1981; Jacoby & Hayman, 1987), lexical decision (Forbach, Stanners, & Hochhaus, 1974; Ratcliff, Hockley, & McKoon, 1985; Scarborough, Cortese, & Scarborough, 1977), word fragment completion (Roediger & Blaxton, 1987; Tulving, Schacter, & Stark, 1982), word meaning comparison (Woltz, 1988, 1990a, 1990b, in press), and text processing (Kolers, 1976; Masson, 1986). In general, the findings from these studies are consistent in suggesting that performance facilitation from repeating a single processing event is long-lasting, quite specific to surface features of the priming event, and not dependent on recall or recognition of the priming event. Many of these studies refer to such facilitation as evidence of *implicit memory*. Implicit memory refers to retention of prior events that is demonstrated in performance facilitation on tasks that do not demand recall of the previous events. In contrast, explicit memory refers to conscious recollection of prior events as demonstrated in traditional measures of recall and recognition.

The purposes of this research were to investigate the nature of individual differences in implicit memory performance as measured by repetition priming and to estimate the relationship of such differences to skill acquisition ability. Given that the construct of implicit memory exists in contrast to the construct of explicit memory, the research reported here has also examined individual differences in repetition priming and skill acquisition as they relate to explicit memory performance. In this report I will first review existing literature relevant to these purposes.

Individual Differences in Implicit and Explicit Memory Measures

Individual Differences in Implicit Measures. Given that implicit memory as measured by repetition priming has been a relatively new topic of study, there is limited evidence regarding individual differences. The evidence that does exist primarily stems from research comparing the magnitude of repetition priming effects for populations known to differ in explicit memory test performance. Both developmental and neurological studies of this type have generally failed to find differences in repetition priming. For example, Light and Singh (1987) and Mitchell (1989) reported that young and old adults who differed on recall and recognition measures did not differ significantly with respect to repetition priming effects. Similarly, a number of studies comparing normal and amnesic subjects have reported little or no difference in implicit memory performance, but large explicit memory differences (e.g., Graf, Squire & Mandler, 1984; Graf & Schacter, 1985; Moscovitch, Winocur, & McLachlan, 1986; Shimamura & Squire, 1984; Warrington & Weiskrantz, 1970).

One explanation for these findings would be that there are no systematic individual differences in implicit memory phenomena. After all, if such extreme groups do not differ, why would one expect differences within more homogeneous groups? Such an interpretation corresponds to Hasher and Zachs' (1979, 1984) assertion that individuals differ systematically on effortful processes but not on most automatic processes. This also corresponds to a theory by Reber (1989) concerning implicit learning and memory. This theory postulates that implicit learning reflects the functioning of more primitive cognitive and memory systems. One implication of the primacy of implicit memory is that individual differences should be minimal. Reber, Walkenfeld, and Hernstadt (1991) reported evidence consistent with this prediction.

However, the evidence by Reber et al. (1991) was based on a single implicit learning task in which subjects received extensive practice. Furthermore, the failure of other studies to find implicit memory differences between extreme groups defined by age or neurological disorder could have other interpretations. One possibility is that there are systematic individual differences in both explicit and implicit memory processes, but that these differences are uncorrelated. Like the first interpretation, this is consistent with theories of independent memory systems underlying explicit and implicit memory phenomena (e.g., Squire, 1986; Tulving, 1983; Tulving & Schacter, 1990). Also like the first interpretation, this would predict a zero correlation between implicit and explicit memory measures within the normal adult population. However, unlike the first interpretation, this implies that implicit memory measures should exhibit reliable individual differences within the normal population, and different implicit memory measures should correlate with one another.

Consistent with the second interpretation, there is some evidence of systematic differences in repetition effects within normal adults. Perruchet and Baveux (1989) reported significant correlations among several implicit and explicit memory measures administered to a sample of 64 French college students. The implicit memory measures included repetition priming in word fragment completion, tachistoscopic word identification, perceptual clarification, and anagrams. The pattern of correlations suggested two classes of repetition priming effects, but there did appear to be systematic individual differences in both classes.

In other research with normal adults, Woltz (1988, 1990a, 1990b; Woltz & Shute, in press) found evidence of systematic individual differences in repetition priming effects for a semantic comparison task (i.e., deciding whether two words have the same meaning). Repetition priming effects showed moderate internal consistency reliability ($.6 < r_{xx'} > .87$) under various trial conditions and repetition lags (Woltz, 1990a, 1990b; Woltz & Shute, in press). Furthermore, the repetition effects had modest correlations with working memory performance (Woltz, 1990a), skill learning (Woltz, 1988), declarative knowledge acquisition (Woltz & Shute, in press), and long-term recognition of previously studied information (Woltz, 1990b).

In summary, previous findings of dissociations between implicit and explicit memory measures with respect to neurological disorders and aging can be interpreted in several ways. They do not necessarily suggest the absence of individual differences in implicit memory within the normal population. Although some theory and evidence suggests minimal individual variability in implicit memory phenomena, other evidence suggests that individual differences in implicit memory phenomena may be more prevalent.

Individual Differences in Explicit Measures. There are two components to the distinction between explicit and implicit memory measurement: (a) conscious or intentional recollection, and (b) memory for a specific experiences in the examinee's personal history. These two components are evident in the following contrast between implicit and explicit memory by Schacter (1987). "Implicit memory is revealed when previous experiences facilitate performance on a task that does not require conscious or intentional recollection of those experiences; explicit memory is revealed when performance on a task requires conscious recollection of previous experiences" (p. 501).

Explicit memory tasks used in research contrasting implicit and explicit memory performance typically have demanded old-new judgments of individual stimuli, half of which had been seen once and half of which were new. This type of task conforms well to the explicit memory definition. Task instructions produce intentional recollection, and subjects attempt to recollect prior events. A question, however, is whether intentionality or event recollection is most important in the previously observed dissociations with implicit memory.

Semantic memory measures, or tests of knowledge that is not event-specific such as vocabulary or general world knowledge, represent an interesting contrast to typical explicit memory tasks. They require intentional recollection, but they do not require recollection of specific events or experiences. Previous investigations of individual differences in semantic and episodic memory performance suggest an interesting dissociation.

Past research has demonstrated reliable individual differences in episodic memory performance that conforms to current definitions of explicit memory. The most ambitious test of individual differences in episodic memory was conducted by Underwood, Boruch, and Malmi (1978) who administered a variety of episodic, semantic, and short-term memory tasks to 200 individuals. Episodic memory tasks included multiple measures (differing primarily in content characteristics) of free recall for word lists, cued recall and recognition of word pairs, and old-new discrimination in word lists and word pairs. Underwood et al. (1978) reported moderate to high alternate-forms reliability estimates for most measures and moderate relationships among tasks, particularly if the tasks had similar retrieval demands. Thus, there was evidence for systematic individual differences in explicit episodic memory processes.

A somewhat surprising additional outcome of the Underwood et al. (1978) work was the finding that episodic memory measures had weak relationships with memory measures such as vocabulary and Scholastic Aptitude Test (SAT) scores that represent semantic knowledge that is not event-specific. In summarizing the correlations between 33 memory measures, Underwood et al. (1978) stated, "One fact that stands out...is that our episodic memory tasks and the semantic memory tasks represent different worlds" (p. 409).

The conclusion by Underwood et al. (1978) that individual differences in episodic and semantic memory measures were unrelated was consistent with earlier findings by Anastasi (1930, 1932). In a series of studies, Anastasi found that cued recall, free recall, and recognition measures of studied verbal and geometric stimuli were correlated among themselves but largely unrelated to semantic knowledge measures such as vocabulary tests. More recently, Cohen (1984) reported evidence for separate episodic and semantic memory factors, although there was evidence for a general factor.

In summary, there is ample evidence concerning reliable individual differences in explicit memory processes as measured by tasks requiring conscious recollection of previous events. Semantic memory measures also require conscious recollection of information, but they do not require event-specific recollections. Even though semantic knowledge measures tend to demonstrate reliable individual differences, past evidence has been consistent in suggesting that episodic and semantic memory differences are relatively uncorrelated.

Past Research and Theory Linking Repetition Priming and Skill Acquisition

As stated above, a primary purpose of this research was to investigate individual differences in implicit memory measures with respect to their possible relationship to differences in skill acquisition. This hypothesized relationship was motivated by two sources of evidence linking simple repetition priming to more complex procedural skill acquisition.

The first body of evidence comes from studies comparing the performance of amnesic patients and normal adults on learning and memory performance (see Shimamura, 1986 for a review). Despite severe deficits in traditional memory measures such as recall and recognition, some classes of amnesics do not differ from normals in (a) skill learning and retention (e.g., mirror tracing and pursuit rotor tasks), and (b) repetition priming (e.g., primed word stem completion and primed fragmented pictures). Squire (1986, 1987) has interpreted this as evidence for independent declarative and procedural memory systems which can be differentially affected by neurological impairment. Of most interest here is the fact that repetition priming was associated with procedural learning rather than other memory functions (Squire, 1986, 1987).

The second source of evidence comes from research on individual differences in skill learning among normal adults. Woltz (1988) found that differences observed in a repetition priming task predicted differences in a cognitive skill learning task. Furthermore, the pattern of relationship between repetition priming and skill performance over practice blocks was independent of the relationships of other cognitive measures such as working memory capacity and semantic knowledge. This evidence suggested that repetition priming processes may play a role during skill acquisition that is unique vis-a-vis other memory processes.

The empirical links between repetition priming and complex skill learning described above also make sense in terms of current theories of skill acquisition. Both a production model (Anderson, 1983, 1987) and an instance theory (Logan, 1988) describe learning mechanisms that correspond to characteristics of repetition priming. Anderson (1983) described *composition* and *proceduralization* as mechanisms whereby more refined productions result from repeated practice. Like repetition priming, these mechanisms are not thought to depend on conscious effortful processes, but result rather automatically from performance. Likewise, Logan (1988) proposed that each processing episode during skill practice results in a separate memory representation, and that skill acquisition depends on the growing data base of such instances in memory (Logan, 1988). Furthermore, Logan (1990) has argued directly that repetition priming may represent the same mechanisms that underlie this accumulation of instances in skill development.

Overview of the Current Research

One testable implication of the proposed common processes involved in repetition priming and complex skill acquisition pertains to patterns of individual difference. That is, if repetition priming represents a memory process fundamental to common forms of complex skill acquisition, then individuals who show greater repetition priming effects should also be those who acquire procedural skills most effectively. Previous research by Woltz (1988) has already offered some evidence to this effect. The research reported here investigated the degree of association between individual differences in repetition priming effects and skill acquisition measures much like the previous work of Woltz (1988). However, the previous work, as well as most other repetition priming or implicit memory research, has been limited by the use of only one priming measure. As a result it is not clear whether previously observed correlations accurately represent the relationship between the repetition priming and skill acquisition or merely a task-specific relationships that could change dramatically when different experimental tasks are used to measure each construct. The current study addressed this past limitation by using three distinct repetition priming tasks and three distinct measures of skill acquisition.

The three measures of repetition priming correspond to recent efforts by the US Air Force's Learning Abilities Measurement Project (LAMP) to develop parallel measures of ability constructs using verbal, spatial (figural), and numeric stimuli and processing demands (Kyllonen, 1991). The verbal repetition priming task was the semantic comparison task used extensively in previous research (Woltz, 1988, 1990a, 1990b, Woltz & Shute, in press). In this task, two words were presented and subjects responded *like* or *different* depending on whether the words had similar meanings (e.g., *moist* = *damp*?). A subset of trials was repeated at varied and unpredictable intervals. Repetition priming was measured by contrasting repeated trial latency with new trial latency. The quantitative repetition priming task was similar to the verbal task except that two numeric expressions were presented for comparison (e.g., *21-8* = *13*?). Similarly, the spatial repetition priming task presented two asymmetric stick-figures for comparison. Subjects responded *like* if the target figure corresponded to a 90 degree rotation of the other figure in the direction indicated by an arrow, and *different* if it did not.

The inclusion of multiple measures allowed for a more complete investigation of the nature of individual differences in implicit memory performance. In addition to internal consistency reliability estimates, this design allowed for an analysis of the generality of individual differences in repetition priming effects across processing domains (i.e., how stable are individual differences in repetition priming when measured under these different processing demands?). While there was similarity among the processing demands of the three repetition priming measures (i.e., all required stimulus comparisons and like-different responses), the encoding and comparison processes were markedly different in each task. Thus, the variance shared between these tasks provided interpretable indexes of the generality of repetition priming differences over different processing demands.

An additional feature of the three priming tasks was the inclusion of explicit memory measures. In each priming task, a subset of the priming trials and an equivalent set of new trials was used in a new-old recognition test that immediately followed the priming trials. The inclusion of these measures allowed (a) the same type of reliability analysis described for repetition priming, (b) estimation of the relationship between differences in implicit and explicit measures for the same processing events, and (c) a comparison of correlations with skill acquisition for implicit and explicit memory measures.

This study also included multiple measures of skill acquisition, thus allowing the same reliability questions to be addressed about individual differences in skill learning. The skill learning tasks were verbal, spatial, and quantitative versions of the task used by Woltz (1988). In these tasks, subjects first studied a complex set of rules used for classifying stimuli. Then they were provided with extensive practice applying the rules such that performance became fast and relatively error free.

By using three different measures each of implicit memory, explicit memory, and skill acquisition, the degree of association between these three constructs could be estimated with greater confidence than was possible in previous research.

METHOD

Subjects

The subjects in this study were 419 US Air Force enlisted personnel in their eleventh day of basic training at Lackland Air Force Base, TX. Approximately 27% of these subjects were eliminated from the study because their data indicated lack of effort (i.e., high error rates and unrealistically low latency scores).[1] Of the remaining 305 subjects, 246 were male and 59 were female.

Apparatus

All experimental tasks were administered on Zenith Z-248 microcomputers with standard keyboards and EGA color video monitors. Software was written to achieve millisecond timing of response latency (Walker, 1985).

Procedure

Subjects were tested in groups of 30-40, with each subject at an individual testing carrel containing a microcomputer. Each subject participated for approximately 3 hr, performing nine tasks. There were three classes of tasks: Repetition priming, new-old recognition, and skill acquisition. Each class of task had three versions representing verbal, quantitative and spatial processing domains.

At the beginning of each session, the subjects were given a general orientation to the experimental procedures and a few minutes of practice locating keys on the computer keyboard. Instructions to all tasks were administered by the computers, and proctors were available to answer questions.

The order of tasks for each subject was randomly determined with the following constraints. The first six tasks were always the priming and recognition tasks, with the priming and recognition tasks for a processing domain occurring together (priming trials then recognition trials). The order of verbal, quantitative, and spatial versions of the

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[1]Although the number of subjects eliminated from the study may seem high in comparison to research conducted with other populations, it was deemed necessary in this population given the unusual circumstances of basic military training. Many subjects report physical fatigue and mental stress during the early phases of basic training. Consequently, many cannot sustain adequate effort for 2.5 to 3 hours of cognitive testing. Given that most measures were of response latency, it seemed unacceptable to include subjects with high error rates indicative of minimal effort. The exclusion of this many subjects probably served to lower the correlation estimates somewhat due to restricting the range of variablility.

priming and recognition tasks was randomized for each subject. The three skill acquisition tasks were always last, with order of these also randomly determined.

Repetition Priming Tasks. The three priming tasks had the same structure with respect to repeated trials. Each task consisted of eight blocks of 35 trials. Within these blocks, repetitions of trials occurred at lags of 1, 6, 36, and 144 trials. Each trial presented the subjects with two stimuli which they had to compare and decide if they were like or different. In all three tasks, subjects were instructed to respond as quickly as possible while maintaining approximately 90% accuracy.

Each block consisted of three warm-up trials followed by four sets of eight trials. Within each 8-trial set there was (a) one Lag 6 repetition that was randomly assigned to either Trials 1 and 7 or Trials 2 and 8, and (b) one Lag 1 repetition that was randomly assigned to two adjacent trials within the Lag 6 trials. The remaining four trials in each 8-trial set were either first or second occurrences of Lag 36 or Lag 144 trials, depending on the block. In odd-numbered blocks, two trials per 8-trial set were first occurrences of Lag 36 repetitions. In even-numbered blocks, two trials per 8-trial set were second occurrences the Lag 36 trials that had their first occurrence in the previous block. In Blocks 1-4, the remaining two trials per 8-trial set were first occurrences of Lag 144 repetitions. In Blocks 5-8, the remaining two trials per 8-trial set were second occurrences of the Lag 144 trials that had their first occurrence presented in Blocks 1-4. For both Lag 36 and Lag 144 repetitions, the second occurrence trials occurred within the same 8-trial set as the first occurrence trials. That is, if the first occurrence trial was presented in the third 8-trial set of a block, the second occurrence trial would also be presented in the third 8-trial set of the appropriate block. Finally, within each block, half of all trials at each lag were positive match trials, and half were negative match trials.

Each trial in each task began with an attention cue (an asterisk) presented for 1000 ms, followed by a blank screen for 500 ms. Then, the trial stimuli were presented and remained on the computer display until the subject responded. In each task, subjects were to compare two stimuli presented together on the display and decide if they were *like* or *different*. The trial stimuli for the verbal, quantitative, and spatial tasks will be described below. Subjects responded by pressing the *L* key for like and the *D* key for different. Feedback was provided following only incorrect responses. The word *WRONG* and a low tone were presented for 2000 ms. A blank display of 1000 ms separated each trial from the attention cue of the subsequent trial. At the end of each block, subjects received summary feedback which displayed their median latency and percent correct for the 35 trials in the block. Instructions to respond as quickly as possible while maintaining 90% accuracy were also repeated at this time.

The Verbal Priming trials each presented two words, one on top of the other separated by a single line in the 24-line display. If the two words were synonyms, subjects responded *L* for like. If they were unrelated in meaning, subjects responded *D* for different. The stimulus pool consisted of 210 sets of three words. Each 3-word set consisted of a stem word, a synonym to the stem, and a word unrelated to the stem. The stimulus sets were constructed such that words were common enough to be a part of most subject's vocabulary. This stimulus pool was randomly assigned for each subject to the various trial conditions (i.e., match type, repetition lag, trial location, etc.).

The Quantitative Priming trials each presented a simple arithmetic expression (e.g., 42 - 11) , and a single number presented below the expression separated by one blank line. If the expression was equivalent to the number, subjects responded *L* for like. If the expression and the number were not equivalent, subjects responded *D* for different. The stimulus pool consisted of 210 unique stimulus sets. Each number from 2 to 97 was used twice as the bottom number in the stimulus, once in a positive match trial and once in a negative match trial. In addition, 18 of these numbers (9 for positive match and 9 for negative match trials) were randomly selected to be used a third time in order to make a total of 210 stimuli. The expressions for the 105 positive match stimulus sets were generated such that a random half contained addition of two numbers and the other half contained subtraction of two numbers. When a positive match trial used addition, its counterpart negative match trial (i.e., the one with the same target number) always used subtraction, and vice versa. The first number in positive match addition expressions was randomly selected from numbers between 1 and n-1, where n was the bottom stimulus. The second number in positive match addition expressions was the difference between the first number of the expression and the bottom stimulus. The first number in positive match subtraction expressions was randomly selected from numbers between n+1 and 99, where n was the bottom stimulus. Again, the second number in positive match addition expressions was the difference between the first number of the expression and the bottom stimulus. The 105 negative match expressions using both addition and subtraction were generated in the same way, except a value between -2 and +2 (excluding 0) was randomly selected to be added to the second number in each expression. This stimulus pool was randomly assigned for each subject to the various trial conditions (i.e., match type, repetition lag, trial location, etc.).

The Spatial Priming trials each presented two line drawings, one on top of the other with an arrow between them indicating a rotation direction. If the figure on the bottom was equivalent to the top figure rotated 90° in the direction indicated by the arrow, subjects responded *L* for like. Otherwise, subjects responded *D* for different. Negative match trials always presented the top figure rotated 90° in the opposite direction.

The line drawings were constructed by connecting points horizontally and vertically (but not diagonally) in a 3x3 grid. Drawings contained between two and five line components, where a line component was the horizontal or vertical connection between two points of the grid. All line components were adjoined to at least one other line component. The line figures were always presented superimposed upon the nine-dot grid, and red "handle" was also displayed at the edge of the grid to help subjects perform the mental rotations. Figure 1 provides an illustration of a Spatial Priming trial using a 4-line stimulus drawing.

The stimulus pool consisted of 210 unique stimuli. Line drawings with from 2 to 5 line components were selected such that stimuli could not be rotations or reflections (on X and Y axis) of one another. This stimulus pool was randomly assigned for each subject to the various trial conditions (i.e., match type, repetition lag, trial location, etc.).

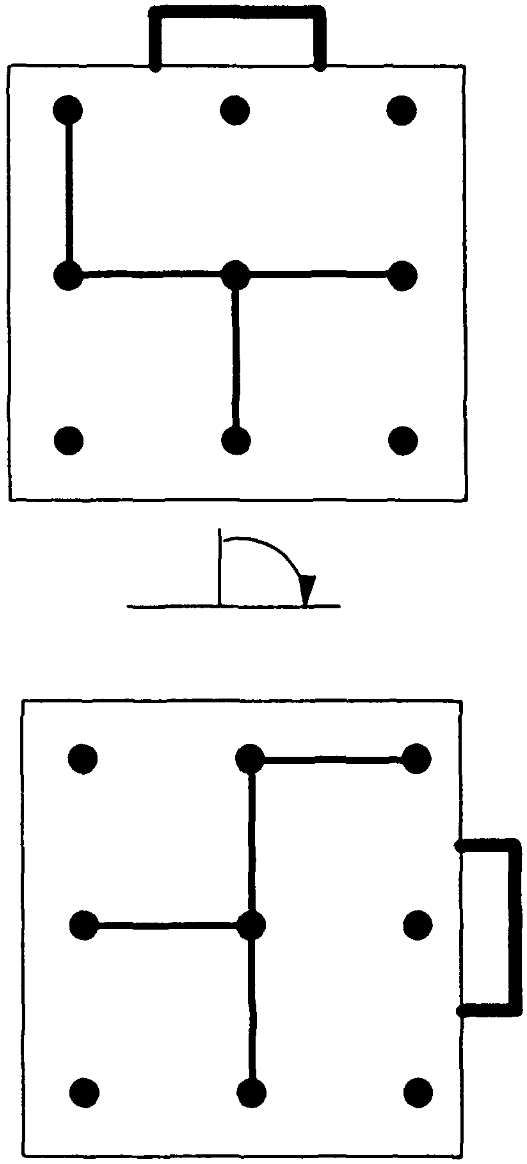

Figure 1: Spatial Priming Task Example Trial

New-Old Recognition Tasks. These three tasks (Verbal, Quantitative, and Spatial Recognition) each consisted of three blocks of 32 trials that directly followed the repetition priming task of the same processing domain. The trial format of each task was similar to that used in the corresponding priming task. A stimulus would be presented just as in the priming task. However, instead of responding *L* or *D* according to whether stimulus components matched, a subject had to decide if the stimulus was one he or she had seen before during the priming task. Subjects responded by toggling with the space bar between *Yes* and *No* boxes at the bottom of the display. Subjects were instructed to press the *Enter* key to register the response after either *Yes* or *No* was highlighted.

Half of the trials in each block were old trials (they had been seen in the priming blocks), and half were new trials. The 48 new trials (16 per block) were randomly selected from the original stimulus pool used for the priming tasks. The old trials were of two types. Half of the 48 old trials (16 per block) were repeats of warm-up trials in the priming trial blocks. These trials had been seen once before.[2] The other half of the old trials were repeats of Lag 36 trials (three from each priming task block). These trials had been seen twice before. Half of all new and half of both types of old trials in each block were positive match trials from the priming task and half were negative match trials. Order of the trials within blocks was randomized for each subject.

Skill Acquisition Tasks. The three skill acquisition tasks (Verbal, Quantitative, and Spatial Skill) were identical in structure, but differed with respect to the stimuli and procedural steps required. Each task consisted of 10 blocks of 32 trials in which subjects practiced applying a set of rules for classifying stimuli. Prior to the 10 blocks of each task, subjects learned a set of decision rules. The rules in each task described which stimulus features belonged together and which did not. Subjects had 1 min to study and memorize the rules to each task. Tables 1,2, and 3 present the stimuli and rules used in the Verbal, Quantitative, and Spatial Skill tasks respectively

The 32 trials per block represented one presentation each of 32 stimuli. Half of the stimuli required an *L* response and half required a *D* response. Subjects were instructed to respond as quickly as possible to each stimulus without making unnecessary errors. No feedback was provided following correct responses, and a low tone and the word *WRONG* were presented for 2000 ms following errors. At the end of each block, subjects were shown their median latency and percent correct for that block.

RESULTS

Both error and latency data were analyzed for the nine tasks in this study. Errors and latency were analyzed separately using the MANOVA approach to repeated measures analysis (see O'Brien & Kaiser, 1985). For latency data, subjects' median latency for each task design cell was the unit of analysis. All statistical tests for mean differences were significance at $p \leq .05$ unless otherwise stated. The criterion for statistical significance of correlations was set at a more conservative level ($p \leq .01$) because of the number of correlations typically evaluated together.

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[2] Note that the three warmup trials at the beginning of each priming task block were not distinguished from the other trials in trial presentation. Consequently, subjects were unaware of the warmup versus actual trial distinction.

Table 1. Stimuli and Rules Used in the Verbal Skill Task

Stimulus Words:

Wheat	Milk	Potato Chip	Pepsi
Banana	Water	Hot Dog	Beer
Almond	Apple Juice	Cheerios	Whiskey
Carrot	Coconut Juice	Candy Bar	Coke
Sand	Molten Lava	Glass	Glue
Leaf	Crude Oil	Paper	Bug Spray
Hair	Sea Water	Plastic	Shampoo
Rock	Blood	Cement	Ink

Rule Sequence:

IF the word is Food, THEN check if its Solid or Liquid
- IF its Solid, THEN press L (for Like)
- IF its Liquid, THEN press D (for Different)

IF the word is NonFood, THEN check if its Synthetic or Natural
- IF its Synthetic, THEN press L (for Like)
- IF its Natural, THEN press D (for Different)

Table 2. Stimuli and Rules Used in the Quantitative Skill Task

Stimulus Numbers:

{-19......-2} {2......19}

Rule Sequence:

IF the number is Negative, THEN check if its Odd or Even
- IF its Odd, THEN press L (for Like)
- IF its Even, THEN press D (for Different)

IF the number is Positive, THEN check if its Big (> |10| or Small (< |10|)
- IF its Big, THEN press L (for Like)
- IF Small, THEN press D (for Different)

Table 3. Stimuli and Rules Used in the Spatial Skill Task

Stimulus Configurations:

Open Circle at Top	Open Circle on Bottom
Filled Circle at Top	Filled Circle on Bottom
Open Square at Top	Open Square on Bottom
Filled Square at Top	Filled Square on Bottom

(There were four stimuli from each category that differed in size.)

Rule Sequence:

IF the figure is on Top, THEN check if its Filled
IF its Filled, THEN press L (for Like)
IF its Unfilled, THEN press D (for Different)
IF the figure is on Bottom, THEN check its Shape
IF its Round, THEN press L (for Like)
IF its Square, THEN press D (for Different)

Repetition Priming Mean Data

Verbal Priming. Mean error and latency data are presented in Table 4 for all first occurrence trials by trial block. Data were collapsed over every two blocks because the balancing of lags was achieved within two-block sets. It was important to look at potential changes in error and latency values over trial blocks for first occurrence trials because priming effects for repeated trial were computed within trial blocks. Of special concern was that Lag 144 repetitions occurred only in Blocks 5-8, whereas repetitions for all other lags occurred in all blocks. For this reason, a univariate contrast between Blocks 1-4 versus Blocks 5-8 was tested following the multivariate test of Block effects.

As seen in Table 4, there was a substantial main effect of match type on the number of errors, $F(1,304) = 271.99$, MSe=11025, with subjects making more errors on positive match trials. Furthermore, there was a significant interaction between trial block and match type on error rate, Approximate $F(3,302) = 13.32$. The univariate test of this interaction for the Block 1-4 vs 5-8 contrast was also statistically significant, $F(1,304) = 29.04$, MSe=33.76. This interaction reflected the fact that in the second half of the trial blocks, subjects exhibited a stronger bias toward negative responses. That is, error rate for negative match trials decreased while it increased for positive match trials.

Table 4. Mean and Standard Deviation of Response Errors and Latency for Verbal Task First Occurrence Trials by Match Type and Trial Block.

	Positive Match		Negative Match	
Trial Blocks	M	SD	M	SD
		Response Errors (%)		
1 & 2	6.69	5.72	4.62	5.19
3 & 4	7.26	6.66	3.36	4.93
5 & 6	8.61	7.94	3.55	5.67
7 & 8	9.02	7.95	3.03	5.55
		Response Latency (ms)		
1 & 2	1394	406	1617	466
3 & 4	1307	368	1478	464
5 & 6	1324	449	1464	497
7 & 8	1329	426	1424	449

There was also a slight tendency for change in response latency across blocks that can be seen in Table 4, Approximate $F(3,302) = 21.54$. Of particular importance, response latency in Blocks 1-4 was greater than that in Blocks 5-8, $F(1,304) = 20.94$, MSe=117680. Furthermore, there was an interaction between block and match type, Approximate $F(3,302) = 271.99$. As seen in Table 4, there was only a 24 ms difference in positive match trials between the first and second half of the blocks, and a 104 ms difference in negative trials between these blocks, $F(1,304) = 35.58$, MSe=27025. As a consequence of these effects, some caution must be used in comparing Lag 144 priming effects with other lags as it is unclear how this reduced latency in later blocks, especially for negative trials, affects the priming estimates.

Table 5 presents priming effects (both error and latency savings) for repeated trials of the Verbal Task by lag and match type. As seen in this table, there were substantial overall priming effects for both errors, $F(1,304) = 526.70$, MSe=32030, and latency, $F(1,304) = 1768.10$, MSe=412089756. For error savings, the effects were greater for positive versus negative trials, $F(1,304) = 305.92$, MSe=17608, and savings decreased with repetition lag, Approximate $F(3,302) = 35.55$. There was also a small but statistically significant interaction between lag and match type, Approximate $F(3,302) = 7.06$, reflecting the fact that error savings declined with lag more in negative compared to positive trials. For the latency data, there was no main effect for match type, $F(1,304) = 1.21$, $p > .05$, but there was a significant interaction between match type and lag, Approximate $F(3,302) = 57.18$. As with the error savings, latency savings declined to a greater extent across lags for negative compared to positive match trials.

Quantitative Priming. Table 6 presents error and latency data for first occurrence trials by trial block and match type. As seen with the Verbal Priming data for first occurrence trials, there was a substantial main effect of match type, $F(1,304) = 64.51$, MSe=3054, and a significant interaction between block and match type, Approximate $F(3,302) = 3.38$. Again, subjects had a bias toward negative responses which increased in later blocks.

The latency data for first occurrence trials in Table 6 also resemble those presented earlier for Verbal Priming. Response latency was longer for negative compared to positive match trials, $F(1,304) = 106.84$, MSe=17308883. Response latency tended to decrease in later blocks, Approximate $F(3,302) = 5.47$, with the difference between Blocks 1-4 and 5-8 being statistically significant, $F(1,304) = 11.68$, MSe=371538. The difference in latency across blocks was also greater for negative compared to positive match trials, Approximate $F(3,302) = 6.78$. There was only a 43 ms difference in positive match trials between the first and second half of the blocks, and a 126 ms difference in negative trials between these blocks, corresponding to significant interaction of Blocks 1-4 versus 5-8 with match type, $F(1,304) = 9.13$, MSe=114770. Thus, as with the Verbal task, these data suggest that Lag 144 priming effects may not be comparable to priming at other lags because of the difference in first occurrence trial performance.

Table 5. Mean and Standard Deviation of Response Error and Latency Savings for Verbal Task Repeated Trials by Match Type and Repetition Lag

	Positive Match		Negative Match	
Trial Lag	M	SD	M	SD
	Response Errors (%)			
1	7.16	4.28	2.37	4.50
6	6.11	4.96	1.43	5.53
36	6.17	4.95	-.05	5.04
144	5.80	6.66	-.01	5.48
	Response Latency (ms)			
1	599	253	673	309
6	395	201	407	226
36	369	184	320	244
144	299	208	224	226

Table 6. Mean and Standard Deviation of Response Errors and Latency for Quantitative Task First Occurrence Trials by Match Type and Trial Block.

	Positive Match		Negative Match	
Trial Blocks	M	SD	M	SD
		Response Errors (%)		
1 & 2	7.82	7.18	6.89	6.47
3 & 4	8.62	7.55	6.34	6.85
5 & 6	7.68	8.28	5.14	6.93
7 & 8	8.44	8.71	5.25	6.98
		Response Latency (ms)		
1 & 2	2549	660	2814	768
3 & 4	2537	768	2691	845
5 & 6	2496	791	2652	875
7 & 8	2504	868	2602	889

Table 7 presents the priming effects found in Quantitative Priming as indicated by both error and latency savings. As with the verbal task, repeated trials produced substantial overall priming effects on response errors, $F(1,304) = 203.79$, $MSe=13926$, and on response latency, $F(1,304) = 1291.18$, $MSe=533220419$.

Priming in the error data was greater for positive compared to negative match trials, $F(1,304) = 29.36$, $MSe=2211$, and it declined with repetition lag, Approximate $F(3,302) = 126.87$. In addition, the decline over lag was slightly greater for positive compared to negative trial repetitions, Approximate $F(3,302) = 5.73$. This interaction was the opposite of that found with the error priming in Verbal Priming where savings for negative match trials showed greater decline over repetition lag.

Priming in the latency data did not differ by match type $F(1,304) = 1.72, p > .05$. Priming did decline with repetition lag, however, Approximate $F(3,302) = 357.99$. These latency effects resembled those found for the Verbal task. In contrast to the Verbal task, however, there was no tendency for latency priming effects in negative match trials to decline more rapidly than those in positive match trials, Approximate $F(3,302) = 1.06, p > .05$.

Spatial Priming. Table 8 presents the first occurrence trial error and latency data by trial block and match type. There was a small but significant main effect of match type on errors in first occurrence trials, with greater errors on positive match trials, $F(1,304) = 7.93$, $MSe=55148$. There was also a significant main effect for block, Approximate $F(3,302) = 10.17$. However, unlike Verbal and Quantitative Priming, there was no interaction between block and match type, Approximate $F(3,302) < 1$. That is, the bias toward negative responses did not increase reliably with blocks. Instead, errors declined for both positive and negative match trials across blocks.

The latency data for first occurrence trials in Table 8 resembles those for Verbal and Quantitative Priming. Response latency was longer for negative compared to positive match trials, $F(1,304) = 52.07$, $MSe=14080037$. Response latency tended to decrease in later blocks, Approximate $F(3,302) = 74.57$, with the difference between Blocks 1-4 and 5-8 being statistically significant, $F(1,304) = 162.39$, $MSe=481305$. The decrease in latency across blocks was also slightly greater for negative compared to positive match trials, Approximate $F(3,302) = 6.39$. There was a 319 ms difference in positive match trials between the first and second half of the blocks, and a 397 ms difference in negative trials between these blocks, corresponding to significant interaction of Blocks 1-4 versus 5-8 with match type, $F(1,304) = 6.67$, $MSe=138579$. Compared to Verbal and Spatial Priming, there appeared to be considerably greater learning across blocks in the Spatial task as indicated by reduction in mean latency of first occurrence trials. Thus, even more than the other priming tasks, these data suggest that Lag 144 priming effects may not be comparable to priming at other lags.

Table 9 presents the priming effects found in Spatial Priming as indicated by both error and latency savings. As with the two other priming tasks, repeated trials produced substantial overall priming effects on response errors, $F(1,304) = 177.62$, $MSe=15939$, and on response latency, $F(1,304) = 743.30$, $MSe=453269871$.

Table 7. Mean and Standard Deviation of Response Error and Latency Savings for Quantitative Task Repeated Trials by Match Type and Repetition Lag

	Positive Match		Negative Match	
Trial Lag	M	SD	M	SD
		Response Errors (%)		
1	7.22	5.06	4.39	5.00
6	3.10	6.56	.43	6.58
36	1.91	6.57	.78	5.82
144	1.13	8.22	.15	7.20
		Response Latency (ms)		
1	1193	558	1196	621
6	343	334	301	361
36	166	336	156	345
144	214	414	171	443

Table 8. Mean and Standard Deviation of Response Errors and Latency for Spatial Task First Occurrence Trials by Match Type and Trial Block.

	Positive Match		Negative Match	
Trial Blocks	M	SD	M	SD
	Response Errors (%)			
1 & 2	9.95	8.66	9.46	8.34
3 & 4	8.66	8.03	7.56	7.82
5 & 6	7.92	8.42	6.94	8.56
7 & 8	8.14	8.67	6.91	8.54
	Response Latency (ms)			
1 & 2	3404	959	3669	1129
3 & 4	3068	876	3184	927
5 & 6	2949	921	3065	906
7 & 8	2885	865	2995	916

Table 9. Mean and Standard Deviation of Response Error and Latency Savings for Spatial Task Repeated Trials by Match Type and Repetition Lag

	Positive Match		Negative Match	
Trial Lag	M	SD	M	SD
	Response Errors (%)			
1	6.60	6.17	5.07	5.54
6	2.77	7.14	2.33	6.52
36	1.23	7.00	.95	6.83
144	.86	8.41	.64	7.81
	Response Latency (ms)			
1	1091	649	936	670
6	395	406	301	422
36	250	359	184	416
144	169	419	123	459

Priming in the error data did not differ between positive and negative match trials, $F(1,304) = 2.62, p > .05$. but it did decline with repetition lag, Approximate $F(3,302) = 118.07$. Unlike, the other priming tasks, there was no difference in decline of priming as a function of match type, Approximate $F(3,302) = 2.51, p > .05$.

Priming in the latency data was generally greater for positive compared to negative match type $F(1,304) = 20.64, MSe=4990185$. Also, as in the other tasks, priming declined with repetition lag, Approximate $F(3,302) = 206.58$. In addition, there was a small but significant interaction between lag and match type, Approximate $F(3,302) = 3.23$. However, unlike the interaction found in Verbal Priming, this interaction reflected a slight tendency for latency priming effects in positive rather than negative match trials to decline more rapidly.

Summary of Priming Effects. The effects of task manipulations were generally consistent across the three priming tasks. In all tasks, subjects demonstrated a bias toward negative responses on first occurrence trials (i.e., there were more errors on positive match trials). This bias, however, corresponded to longer average latency on negative match trials. There was also a significant practice effect in each task, with subjects responding more quickly to first occurrence trials in later blocks, especially on negative match trials.

Of primary importance, each task show substantial priming effects on repeated trials. Priming was evident in both error and latency data. In addition, all priming effects declined with repetition lag in the three tasks. However, because of the changes in first occurrence trial performance across blocks, Lag 144 priming effects were not directly comparable to priming effects at other lags.

Recognition Mean Data

Verbal Recognition. Table 10 presents the mean recognition errors and d' scores for Verbal Recognition. The mean errors for old and new trials suggested that subjects exhibited bias with respect to positive and negative match trials. The interaction between exposure (old vs. new) and match type was significant, $F(1,304) = 122.41, MSe= 134$. Thus, subjects made more errors on new positive match trials (i.e., they had a tendency to say *old* on positive match trials), and they made more errors on old negative match trials (i.e., they had a tendency to say *new* on negative match trials).

The d' means in Table 10 suggest that while subjects generally were quite accurate at distinguishing old trials from new trials, their performance depended on both number of exposures and match type. As expected, subjects were considerably more accurate at recognizing trials that they had seen twice compared to trials that they had seen just once, $F(1,304) = 545.29, MSe=341$. Subjects were also more accurate in their old-new discrimination for positive compared to negative match trials, $F(1,304) =64.10$, $MSe=64.98$, and the advantage for positive trials depended to some extent on the number of exposures, $F(1,304) =39.81, MSe=21.82$. As seen in Table 10, there was a greater discrepancy between positive and negative match trials when they had been seen once versus twice.

Table 10. Mean and Standard Deviation of Percent Error and d' for Verbal Old-New Recognition Trials by Match Type and Number of Exposures.

Prior Exposures	Percent Error		d'	
	M	SD	M	SD
		Positive Match		
0 (New)	15.60	14.79	----	----
1 (Old)	11.53	11.59	2.91	1.24
2 (Old)	4.18	8.25	3.70	1.24
		Negative Match		
0 (New)	12.96	12.96	----	----
1 (Old)	28.06	18.80	2.18	1.18
2 (Old)	7.79	12.02	3.50	1.37

Quantitative Recognition. Table 11 presents the recognition error and *d'* mean data for Quantitative Recognition. As in the verbal data, subjects showed a slight bias toward responding *old* to positive match trials and *new* to negative match trials, as indicated by the Old-New x Match Type interaction, $F(1,304) = 152.10$, $MSe = 348$.

The overall error rates and *d'* means revealed that distinguishing old from new quantitative trials was considerably more difficult than in Verbal Recognition. However, the overall d' mean for the sample was significantly different from zero, $F(1,304) = 115.30$, $MSe = 178$. As with verbal task data, discrimination depended on the number of exposures, $F(1,304) = 112.03$, $MSe = 34$, and on match type, $F(1,304) = 6.28$, $MSe = 3$. The interaction between exposures and match type was not significant, $F(1,304) < 1$.

Spatial Recognition. Table 12 presents the recognition error and *d'* mean data for Spatial Recognition. As in the verbal and quantitative tasks, subjects showed a slight bias toward responding *old* to positive match trials and *new* to negative match trials, as indicated by the Old-New x Match Type interaction, $F(1,304) = 46.09$, $MSe = 208$.

The overall error rates and *d'* means were intermediate between the Verbal and Quantitative Recognition means. As with the other two tasks, discrimination depended on the number of exposures, $F(1,304) = 378.88$, $MSe = 152$, and on match type, $F(1,304) = 6.29$, $MSe = 3$. The interaction between exposures and match type was not significant, $F(1,304) = 1.30$, $p > .05$.

Summary of Recognition Effects. There was considerable consistency across recognition tasks in the effects of task variables. In all three tasks there was a significant bias toward subjects responding *old* to positive match trials and *new* to negative match trials. Subjects' ability to discriminate old from new trials as measured by *d'* was significantly different from zero in all tasks, however this discrimination was considerably higher in the verbal task compared to the other two. Finally, in all tasks subjects showed greater recognition ability for old trials that they had seen twice compared to those they had seen just once.

Skill Learning Mean Data

Data from the skill tasks were examined with respect to overall error rates and the fit of the power law of practice (Newell & Rosenbloom, 1981). The power function,

$$RT = aT^{-b}, \qquad \text{(Eq. 1)}$$

was fitted by least squares nonlinear regression to both sample mean and individual data, where *RT* represents mean response time, *T* represents time of practice (block), and *a* and *b* are model parameters representing initial performance and rate of learning respectively.

Verbal Skill. Error rate for Verbal Skill was $M = 26.29\%$ ($SD = 14.68$) for the initial trial block. After the third block, all block mean errors were below 10%, and the final block error rate was $M = 4.23\%$ ($SD = 4.43$).

Figure 2 presents the mean latency data by block for Verbal Skill fitted by a power function. The standard error of each mean was plotted. As seen in this figure, there was dramatic improvement in response latency over the ten trial blocks, and this improvement was fitted well by the power law of practice. The fit of a power function was also quite good at the level of individual subjects. The mean R^2 value for power functions fitted to block median data by nonlinear regression was $M = .78$ ($SD = .20$).

Table 11. Mean and Standard Deviation of Percent Error and d' for Quantitative Old-New Recognition Trials by Match Type and Number of Exposures.

Prior Exposures	Percent Error M	Percent Error SD	d' M	d' SD
	Positive Match			
0 (New)	56.22	17.45	----	----
1 (Old)	35.38	18.14	.26	.75
2 (Old)	26.15	16.54	.60	.92
	Negative Match			
0 (New)	45.37	17.45	----	----
1 (Old)	47.92	18.66	.17	.70
2 (Old)	37.57	18.65	.50	.80

Table 12. Mean and Standard Deviation of Percent Error and d' for Spatial Old-New Recognition Trials by Match Type and Number of Exposures.

Prior Exposures	Percent Error		d'	
	M	SD	M	SD
	Positive Match			
0 (New)	52.88	17.09	----	----
1 (Old)	35.63	16.62	.32	.61
2 (Old)	19.10	14.35	1.07	.94
	Negative Match			
0 (New)	49.14	15.10	----	----
1 (Old)	41.78	17.46	.26	.58
2 (Old)	24.86	17.04	.92	.88

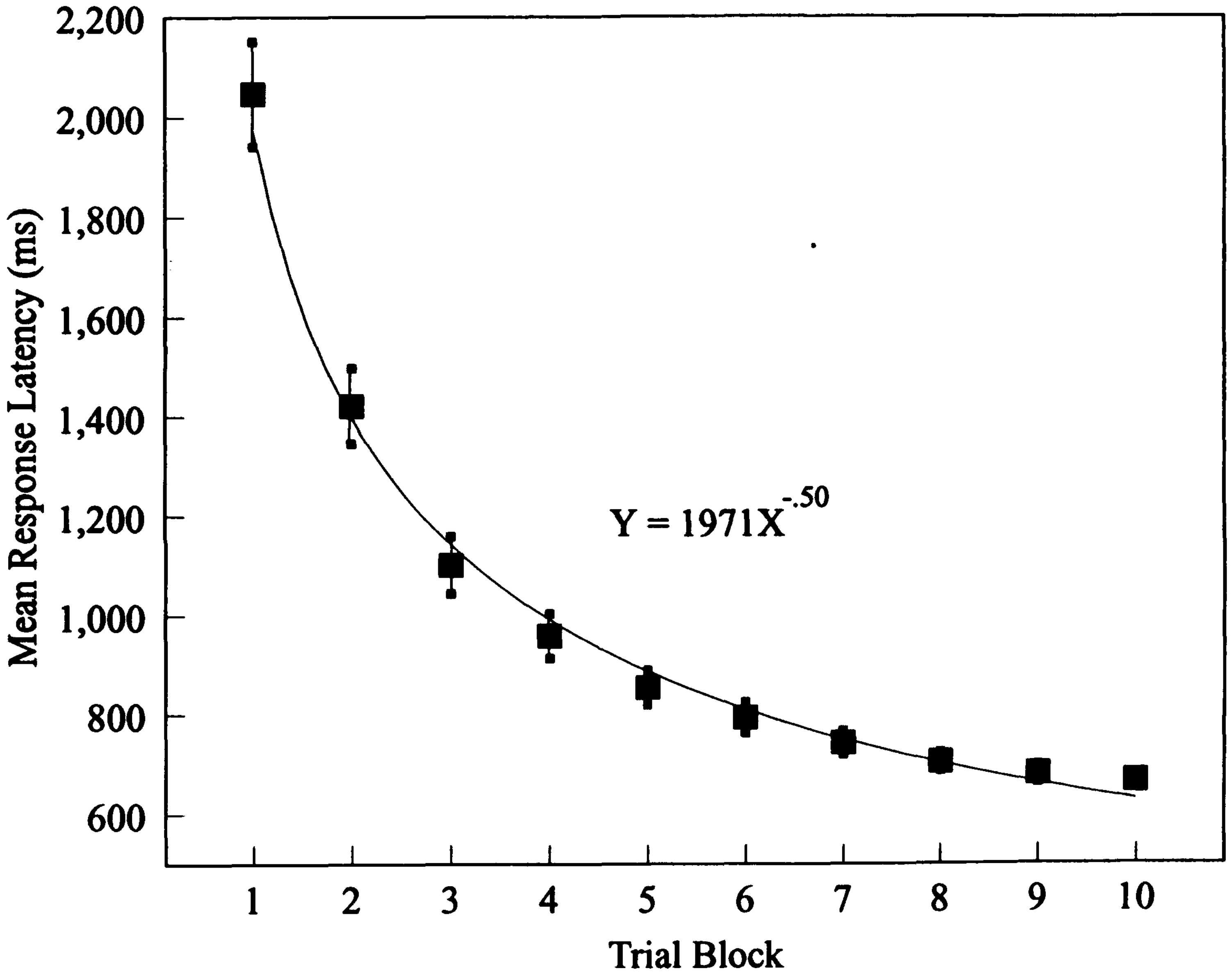

Figure 2: Mean and 95% Confidence Interval of Latency Scores by Trial Block for the Verbal Skill Task

Quantitative Skill. Error rate for Quantitative Skill was *M*=82.56 (*SD*=14.59) for the initial trial block. After the second block, all mean error rates were below 10%, and the final block error rate was *M*=95.38 (*SD*=4.65).

Figure 3 presents the mean latency data by block for Quantitative Skill fitted by a power function. Again, the standard error was plotted around each block mean. The improvement in response latency over the ten trial blocks was not as dramatic as in Verbal Skill, nevertheless it was still fitted well by a power function. The power function fit was also reasonably good at the level of individual subjects. The mean R^2 value for power functions fitted to block median data by nonlinear regression was *M*=.63 (*SD*=.25).

Spatial Skill. Error rate for Spatial Skill was *M*=77.87 (*SD*=13.50) for the initial trial block. After the second block, all mean error rates were below 10%, and the final block error rate was *M*=95.37 (*SD*=3.99).

Figure 4 presents the mean latency data by block for Spatial Skill fitted by a power function. The standard error is plotted around each block mean. The improvement in response latency over the ten trial blocks was similar to that found in Quantitative Skill, and it was fitted well by a power function. Again, the power function fit was also reasonably good at the level of individual subjects. The mean R^2 value for power functions fitted to block median data by nonlinear regression was *M*=.64 (*SD*=.25).

Individual Differences in Repetition Priming

Priming effects for individual subjects were expressed as least squares regression residuals for the purpose of analyzing individual differences. Within each priming task, repeated trial median latency was regressed on first occurrence trial median latency within block set, match type, and lag. Residuals for each subject resulting from these regressions were taken to represent relative priming effects. A negative residual represented repeated trial latency that was shorter than expected given first occurrence latency (i.e., a relatively large priming effect). Conversely, a positive residual represented repeated trial latency that was longer than expected given first occurrence latency (i.e., a relatively small priming effect).

Within each priming task, there were 28 residual scores computed for each subject. Lags 1, 6, and 36 each had eight residual scores (4 block sets x 2 match types). Lag 144 had four residual scores (2 block sets x 2 match types). The 24 residual scores for Lags 1, 6, and 36 were completely independent estimates of priming as they were computed on unique sets of trials. The four residual scores for Lag 144, however, cannot be considered completely independent from the other lags. Because of the difference between first occurrence trial performance in Blocks 1-4 versus 5-8, it was deemed inappropriate to use Lag 144 first occurrence trial latency from Blocks 1-4 and second occurrence trial latency from Blocks 5-8. Residuals from these regressions would have reflected differences in mean latency change over blocks as well as repetition priming. Instead, Lag 144 repeated trial median latency was regressed on all first occurrence trials within the concurrent block set (i.e., first occurrence trials from Lags 1, 6, and 36 in Blocks 5-8). Thus, Lag 144 residuals were not completely independent from residuals from the other lags. As a result, correlations with other lags should be slightly inflated.

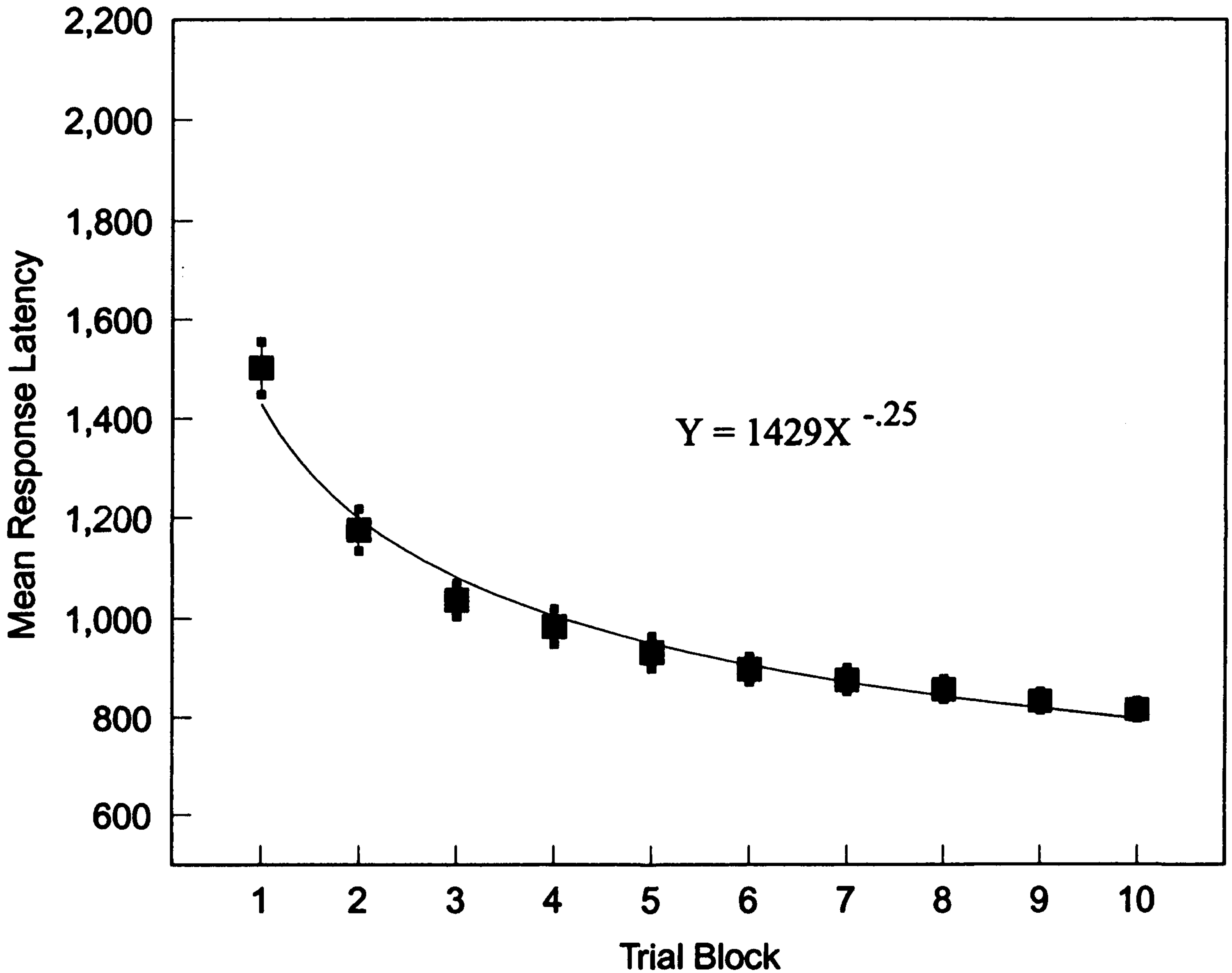

Figure 3: Mean amd 95% Confidence Interval of Latency Scores by Trial Block for the Quantitative Skill Task

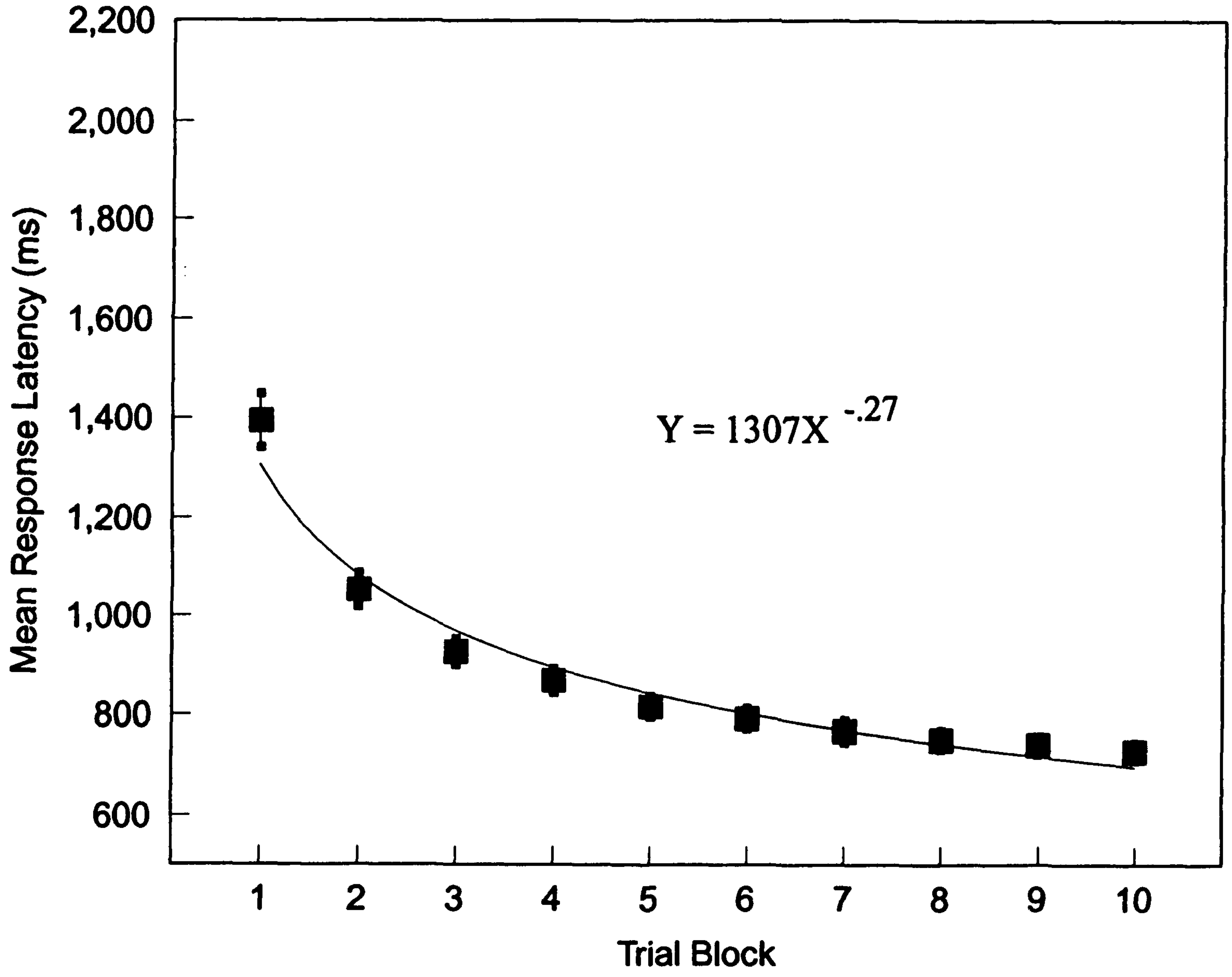

Figure 4: Mean and 95% Confidence Interval of Latency Scores by Trial Block for the Spatial Skill Task

Table 13 presents the intercorrelations and alpha reliability estimates for residual scores from Verbal Priming. As seen here, the internal consistency of residual scores within each lag was reasonably high (recall that there were only eight observations for Lags 1, 6, and 36 and four observations for Lag 144). The interrelationships between lags were also reasonably high, given the reliability estimates. When disattenuated for the estimated unreliability due to item content, most of these correlations were in the high .80's and .90's. Also evident in Table 13 was a simplex pattern, where priming at any given lag was most closely related to priming at adjacent lags.

Table 14 presents the intercorrelations and alpha reliability estimates for residual scores from Quantitative Priming. The internal consistency estimates of residual scores within each lag were lower than those for Verbal Priming, except at Lag 1. The interrelationship of priming between lags was also lower as expected given the greater measurement error.

Table 15 presents the intercorrelations and alpha reliability estimates for residual scores from Spatial Priming. Here the internal consistency estimates of residual scores within each lag were higher than those from Quantitative Priming, but not as high as those from Verbal Priming. The interrelationship of priming between lags was also reasonably high, given the reliability estimates.

Individual Differences in Old-New Recognition

Table 16 presents the intercorrelations for *d'* scores from Verbal Recognition. All correlations in this matrix were of approximately the same magnitude. The alpha reliability estimate for the composite of these four variables was alpha = .75, suggesting a moderately homogenous measure of new-old recognition ability.

Table 17 presents the intercorrelations for *d'* scores from the Quantitative New-Old recognition task. As with the Verbal Recognition task, these variables all had moderate correlations with one another. The alpha reliability estimate for the composite of these four variables was alpha = .71, suggesting a moderately homogenous measure of new-old recognition ability.

Table 18 presents the intercorrelations for *d'* scores from the Spatial New-Old recognition task. These correlations were somewhat lower than those found in the Verbal and Quantitative Recognition tasks. Correspondingly, the alpha reliability estimate for a composite of these four variables was alpha=.49, suggesting a less homogenous measure of new-old recognition ability. Thus, measurable individual differences were not as evident in the spatial explicit memory task as they were in the three implicit memory tasks and the other two explicit memory tasks.

Relationships Among Priming and Recognition Measures

Table 19 presents the intercorrelations and alpha reliability estimates for composite scores from all three priming and all three recognition tasks. The alpha reliability estimates represent the homogeneity of all scores computed within each task. For the three priming tasks, there were 28 separate residual scores as described earlier. For the recognition tasks, there were four separate *d'* scores. As seen in this table, the internal consistency of the composite scores was reasonably high, except for the Spatial Recognition *d'* score.

Table 13. Intercorrelations and Alpha Reliability Estimates for the Verbal Priming Task Latency Savings Residual Scores by Repetition Lag

	Lag 1	Lag 6	Lag 36	Lag 144
Lag 1	(.69)			
Lag 6	.56	(.58)		
Lag 36	.51	.58	(.65)	
Lag 144	.35	.57	.58	(.63)

Note: Diagonal Correlations are alpha reliability estimates. Correlations of .15 and larger are significant at $p < .01$.

Table 14. Intercorrelations and Alpha Reliability Estimates for the Quantitative Priming Task Latency Savings Residual Scores by Repetition Lag

	Lag 1	Lag 6	Lag 36	Lag 144
Lag 1	(.80)			
Lag 6	.31	(.41)		
Lag 36	.17	.37	(.57)	
Lag 144	.19	.43	.47	(.29)

Note: Diagonal Correlations are alpha reliability estimates. Correlations of .15 and larger are significant at $p < .01$.

Table 15. Intercorrelations and Split-half Reliability Estimates for the Spatial Priming Task Latency Savings Residual Scores by Repetition Lag

	Lag 1	Lag 6	Lag 36	Lag 144
Lag 1	(.82)			
Lag 6	.37	(.51)		
Lag 36	.25	.50	(.57)	
Lag 144	.29	.52	.44	(.37)

Note: Diagonal Correlations are alpha reliability estimates. Correlations of .15 and larger are significant at $p < .01$.

Table 16. Intercorrelations for the Verbal New-Old Recognition Scores (d') by Match Type and Number of Exposures

	Neg. 1 Exp.	Pos. 1 Exp.	Neg. 2 Exp.	Pos. 2 Exp.
Neg. 1 Exp.	---			
Pos. 1 Exp.	.42	---		
Neg. 2 Exp.	.46	.38	---	
Pos. 2 Exp.	.45	.34	.50	---

Note: Correlations of .15 and larger are significant at $p < .01$.

Table 17. Intercorrelations for the Quantitative New-Old Recognition Scores (d') by Match Type and Number of Exposures

	Neg. 1 Exp.	Pos. 1 Exp.	Neg. 2 Exp.	Pos. 2 Exp.
Neg. 1 Exp.	---			
Pos. 1 Exp.	.37	---		
Neg. 2 Exp.	.34	.42	---	
Pos. 2 Exp.	.34	.48	.39	---

Note: Correlations of .15 and larger are significant at $p < .01$.

Table 18. Intercorrelations for the Spatial New-Old Recognition Scores (d') by Match Type and Number of Exposures

	Neg. 1 Exp.	Pos. 1 Exp.	Neg. 2 Exp.	Pos. 2 Exp.
Neg. 1 Exp.	---			
Pos. 1 Exp.	.11	---		
Neg. 2 Exp.	.19	.19	---	
Pos. 2 Exp.	.23	.20	.24	---

Note: Correlations of .15 and larger are significant at $p < .01$.

Table 19. Intercorrelations and Alpha Reliability Estimates for the Latency Savings Residual Scores and d' Recognition Scores for Verbal, Quantitative, and Spatial Tasks

	V-Prime	Q-Prime	S-Prime	V-Recog.	Q-Recog.	S-Recog.
V-Prime	(.85)					
Q-Prime	.31	(.77)				
S-Prime	.28	.38	(.81)			
V-Recog.	.46	.30	.13	(.75)		
Q-Recog.	.14	.23	.12	.25	(.71)	
S-Recog.	.15	.18	.19	.20	.17	(.49)

Note: Diagonal Correlations are alpha reliability estimates. All correlations between priming and recognition variables were negative, but the sign was dropped for simplicity. Correlations of .15 and larger are significant at $p < .01$.

The pattern of intercorrelations in Table 19 can be interpreted following the logic of multitrait-multimethod analysis first proposed by Campbell and Fiske (1959), where processing domain (verbal, quantitative, and spatial) is substituted for method. The intercorrelations of the three priming scores and the intercorrelations of the three recognition scores represent same trait (i.e., memory process) - different domain correlations. If differences in the two memory processes are more robust than differences in processing capability within domain, then these correlations should be the highest in the matrix. Furthermore, the different trait correlations (i.e., priming measures with recognition measures) represent the relationship between two different memory processes that have exhibited other forms of dissociation. Thus, these correlations may be expected to not differ from zero if in fact implicit and explicit process are independent.

The intercorrelations among the priming measures were some of the highest in the matrix. Quantitative and Spatial Priming had higher correlations with each other (and with Verbal Priming) than with any of the recognition measures. However, Verbal Priming was more highly correlated with Verbal Recognition than it was with either of the other priming measures. Thus, the evidence is not overwhelming, but some evidence exists for priming ability that generalizes across processing domains.

In contrast to the priming measure intercorrelations, the correlations among the recognition measures were all equal to or lower than the same domain - different trait correlations. This suggested that explicit memory performance ability did not generalize as well across processing domain.

The different-trait correlations were generally low and not significantly different from zero when measured with different task content. Only the Quantitative Priming measure had statistically significant correlations with recognition performance measured with different content. In contrast, correlations between priming and recognition within processing domains produced statistically significant correlations, and in the case of the verbal tasks, produced the highest correlation in the matrix. Thus, implicit and explicit memory measures appeared independent only when processing domain (and task) differed.

In total the patterns of correlations suggested (a) that explicit memory performance differences were specific to task content, (b) implicit memory performance differences also showed specificity to task content, but there was also a trend for subjects who showed large priming effects in one domain to show large priming in other domains, and (c) implicit and explicit memory performance differences were not independent when measured with common task content.

Individual Differences in Skill Acquisition

Individual differences in skill acquisition were examined in two ways: Analysis of (a) parameters of a power function fitted to individual subjects, and (b) average performance by trial block (see Ackerman, 1987 for a discussion of these two approaches).

Table 20 presents the intercorrelations and reliability estimates for the two parameters of the power function fitted to individual subject data. Reliability of the parameters was estimated by fitting the model to block means computed on odd and even trials separately. The reliability coefficients in Table 20 represent the correlations of these two estimates for each parameter adjusted by the Spearman-Brown formula. As can be seen in Table 20, the parameter estimates were quite reliable across different item sets within a task. The generalizability of parameter estimates across items from different tasks was much lower. However, the cross-task correlations suggest some degree of generality. That is, the intercorrelations of the same parameter estimated from different tasks were generally higher than the intercorrelations of different parameter estimates from different tasks. This was especially true for the a parameter (i.e., initial performance level).

The reliability estimates for measures of performance level by block were also quite reliable. Split-half reliability estimates for median latency scores by block ranged from .91 to .96 for Verbal Skill, from .89 to .93 for Quantitative Skill, and from .84 to .90 for Spatial Skill. The variations in reliability across blocks were not systematic. That is, the reliability of early blocks did not differ systematically from the reliability of later blocks in any of the three tasks.

The intercorrelations among performance averages by block from different skill tasks are presented in Table 21. For simplicity, performance level indexes were computed over the four quarters of trial performance in each task. As can be seen in Table 21, performance indexes generally had higher correlations within the same task rather than across tasks. However, early and late performance indexes within a task generally correlated no higher than did either early or late indexes across tasks. Again, this suggested task or domain specificity as well as a modest degree of generality of performance indexes across tasks.

Table 20. Intercorrelations and Split-half Reliability Estimates for the Power Function Parameters Estimated from the Verbal, Quantitative, and Spatial Skill Tasks

	V-A	Q-A	S-A	V-B	Q-B	S-B
V-A	(.94)					
Q-A	.32	(.90)				
S-A	.48	.40	(.91)			
V-B	-.71	-.20	-.28	(.91)		
Q-B	-.16	-.73	-.19	.29	(.87)	
S-B	-.39	-.30	-.82	.38	.29	(.88)

Note: Diagonal Correlations are split-half reliability estimates. Correlations of .15 and larger are significant at $p < .01$.

Table 21. Intercorrelations for Median Latency Values for the Four Quarters of the Verbal, Quantitative, and Spatial Skill Tasks

	V1	V2	V3	V4	Q1	Q2	Q3	Q4	S1	S2	S3	S4
V1	--											
V2	.73	--										
V3	.52	.82	--									
V4	.46	.72	.87	--								
Q1	.37	.31	.27	.22	--							
Q2	.36	.39	.38	.38	.70	--						
Q3	.39	.41	.40	.44	.61	.90	--					
Q4	.34	.40	.42	.50	.52	.78	.90	--				
S1	.49	.42	.36	.38	.45	.38	.38	.42	--			
S2	.30	.33	.31	.37	.34	.37	.40	.44	.69	--		
S3	.25	.31	.32	.38	.26	.32	.37	.40	.50	.79	--	
S4	.25	.36	.39	.48	.21	.35	.43	.47	.48	.75	.88	--

Note: Correlations of .15 and larger are significant at $p < .01$.

Relationships between Repetition Priming, Recognition, and Skill Acquisition

First, the overall relationships of Priming, and Recognition with Skill Acquisition were investigated by forming composites from the verbal, quantitative, and spatial tasks of each construct. In addition, a measure that represents reasoning and/or working memory was available from the Armed Services Vocational Aptitude Battery (ASVAB) scores that were available for all but four subjects. A composite of the Arithmetic Reasoning and Math Knowledge subtest scores was created to represent working memory and reasoning (WM/Reasoning) because these subtests have been shown in previous research to have the highest correlations of any ASVAB subtests with other reasoning and working memory tests (e.g., Kyllonen & Christal, 1990). It was possible to create other composites from the ASVAB subtests (e.g., knowledge), but these did not have correlations with the skill tasks that were significant or that differed from the WM/Reasoning composite. So, for simplicity of presentation, only the WM/Reasoning composite from the ASVAB will be presented.

Despite the relatively high reliability of the power function parameters, these values were not predictable by priming, recognition, or reasoning/working memory variables. All within-domain correlations between the parameters and these variables were non-significant ($p > .01$). Thus, when skill acquisition was represented by parameters from the power function, there appeared to be no relationships with either implicit or explicit memory measures (or working memory).

Figure 5 presents the correlations of composite scores for Priming, Recognition, and WM/Reasoning with performance accuracy in the skill acquisition tasks by trial block. Clearly, the only variable that predicted performance accuracy at any time during learning was WM/Reasoning. Moreover, there was a clear pattern of linear decrease across blocks. This pattern was consistent with previous findings showing that measures of working memory and reasoning predicted differences in early stages of skill acquisition when working memory demands are presumably highest (Ackerman, 1988, 1990; Woltz, 1988). Yet, by the final trial blocks, WM/Reasoning had virtually no predictive power in explaining individual differences in performance accuracy. The correlations of the explicit and implicit memory composites were non significant for most trial blocks, with no pattern of increase.

Figure 6 shows the pattern of correlations of Priming, Recognition, and WM/Reasoning with average performance latency across the three skill learning tasks. The pattern of correlations was quite different from that seen with performance accuracy. First, WM/Reasoning had increasing correlations through the early blocks, then decreasing correlations during the later blocks. This again was consistent with earlier findings (Woltz, 1988). Initial block latency was not predicted well by working memory measures, presumably because subjects were still acquiring the declarative knowledge about the rules (i.e., error rate was relatively high). However, as errors decreased, working memory measures predicted differences in latency through the middle phases of performance. With more extended practice, however, the differences between individuals in the ultimate level of skill acquired was not predicted as well by working memory or reasoning measures (also see Ackerman, 1988, 1990).

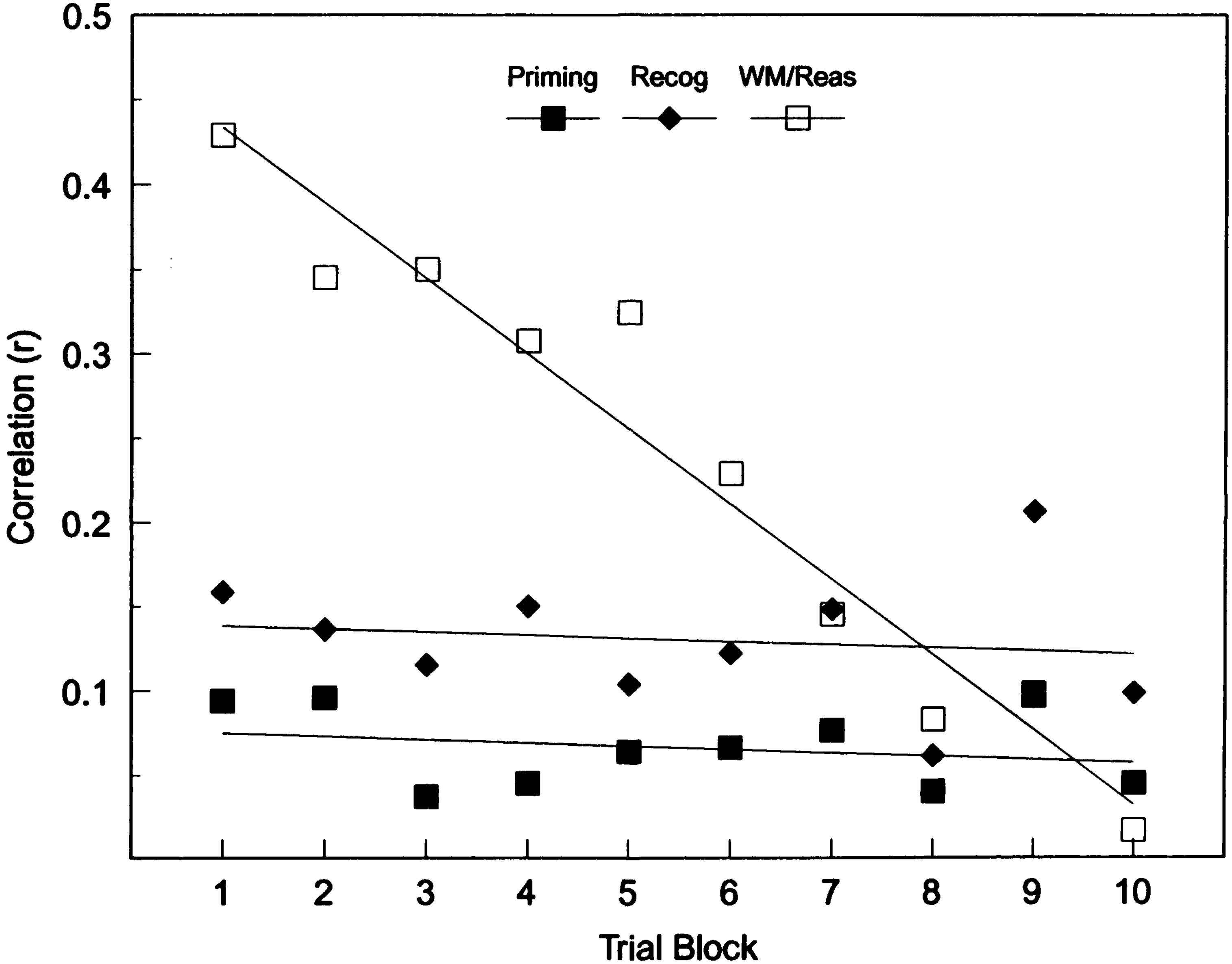

Figure 5: Correlations between Skill Task Accuracy and Priming, New-Old Recognition, and WM-Reasoning Scores by Trial Block

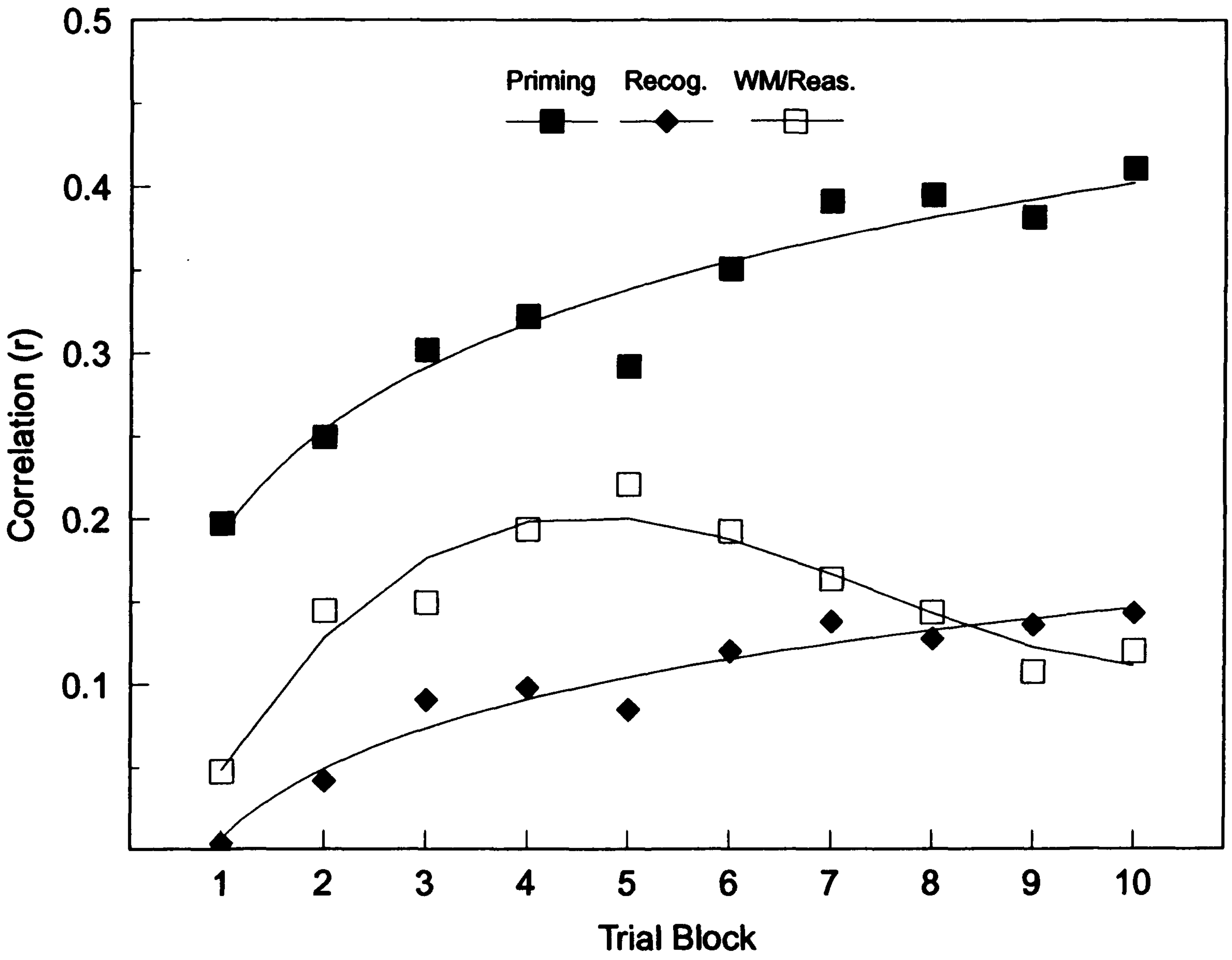

Figure 6: Correlations between Skill Task Latency and Priming, New-Old Recognition, and WM-Reasoning Scores by Trial Block

Recognition showed a pattern of increasing correlation with performance latency over trial blocks. However, the magnitude of these correlations was quite low, with individual correlations not reaching statistical significance ($p \leq .01$) at any block.

Finally, Priming showed a clear pattern of increasing correlations with performance latency over trial blocks with ending correlations of moderate magnitude. This again was consistent with previous evidence (Woltz, 1988). These data suggested that although differences in skilled performance after extensive practice were not predicted by more general ability measures such as working memory and reasoning, they were predicted by differences in implicit memory or repetition priming ability. One explanation for this pattern is that the performance improvements that accrue from repetition practice of already learned performance rules are dictated by the facilitation from each and every repetition of the task. Presumably, such differences in facilitation from individual repetitions was directly measured by the repetition priming tasks.

Finally, the predictive power of Priming was investigated with respect to variations in task content. Figure 7 shows the correlations of all three priming measures with Verbal Skill task latency by block. Here, both Verbal and Quantitative Priming had equivalent predictive power which increased over blocks. Spatial Priming had low correlations for all blocks. Figure 8 shows the correlations of all three priming measures with Quantitative Skill task latency by block. Here, Quantitative Priming had the highest predictive power for most blocks. In contrast to the Verbal Skill task (Figure 7), the Spatial Priming measure showed modest correlations that increased across blocks for the last half of the task. Also, by the final trial block, Verbal Priming's correlation with Quantitative Skill performance approached the same magnitude of that by Quantitative Priming. Finally, Figure 9 shows the correlations of the three priming measures with Spatial Skill task latency by block. Here all three priming measures showed equivalent correlations that increased modestly across trial blocks.

The evidence was somewhat mixed, but there were some indications that the content specificity of priming observed in correlations between priming and recognition also influenced correlations of priming with skill task performance. This was most evident in correlations with the Quantitative Skill task, and to a lesser extent with the Verbal Skill task. The lack of content specificity of the Spatial Priming and Skill tasks may in part be due to the variability of processing strategies typically employed by subjects in performing spatial tasks. Earlier research has demonstrated that some subjects, especially those low in spatial ability, employ non spatial strategies in solving "spatial" problems (e.g., Kyllonen, Lohman, & Snow, 1984; Kyllonen, Lohman, & Woltz, 1984).

DISCUSSION

The three primary purposes of this research were to investigate (a) the consistency of individual differences in repetition priming both within and across processing domains, (b) the relationship of differences in repetition priming (an implicit memory measure) to differences in episodic recognition (an explicit memory measure), and (c) the relationship between differences in repetition priming to differences in cognitive skill acquisition. The results pertaining to these issues will be summarized here, as well as the implications of these findings to current theory and future research questions.

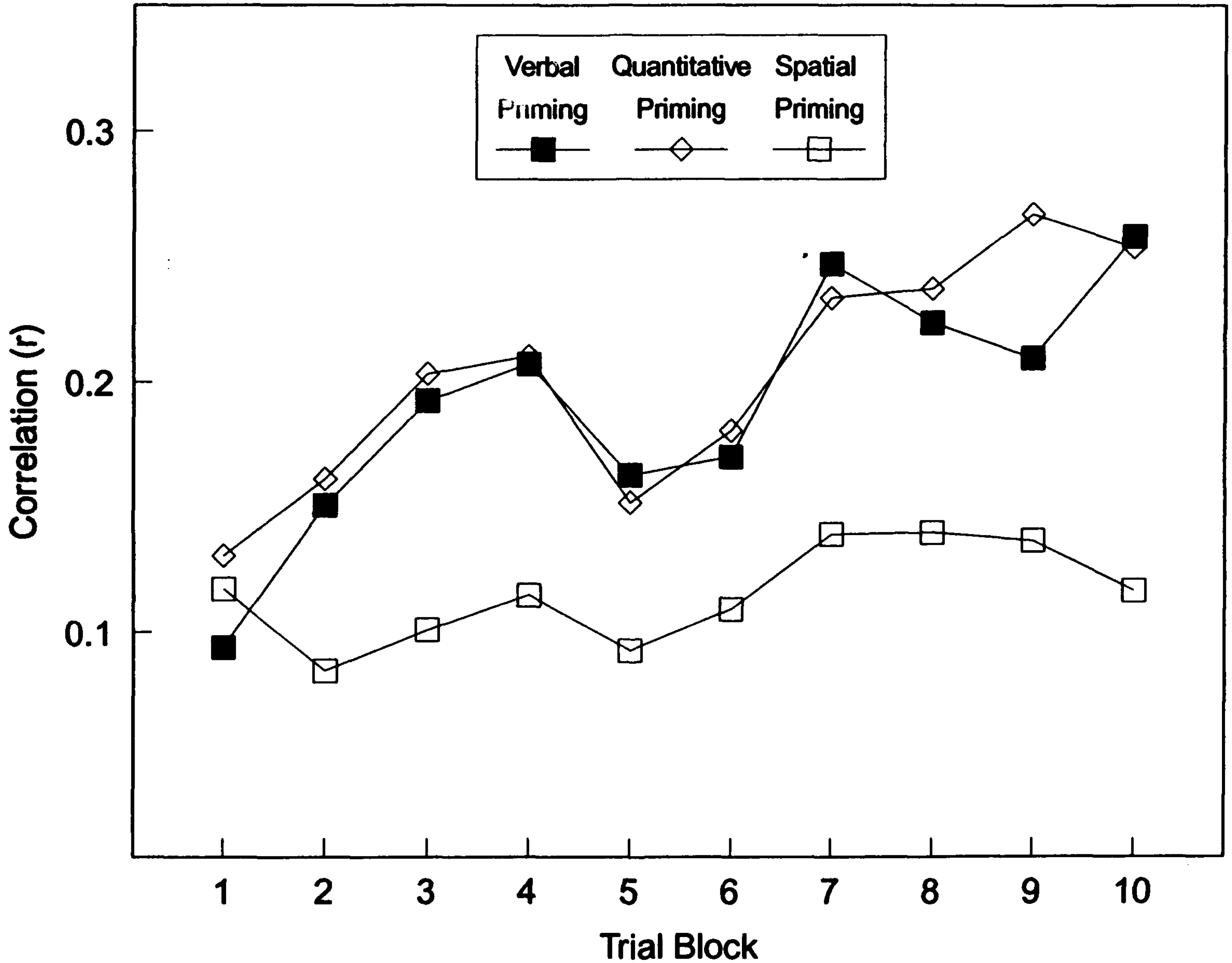

Figure 7: Correlations of Verbal Skill Task Latency and Priming by Processing Domain and Trial Block

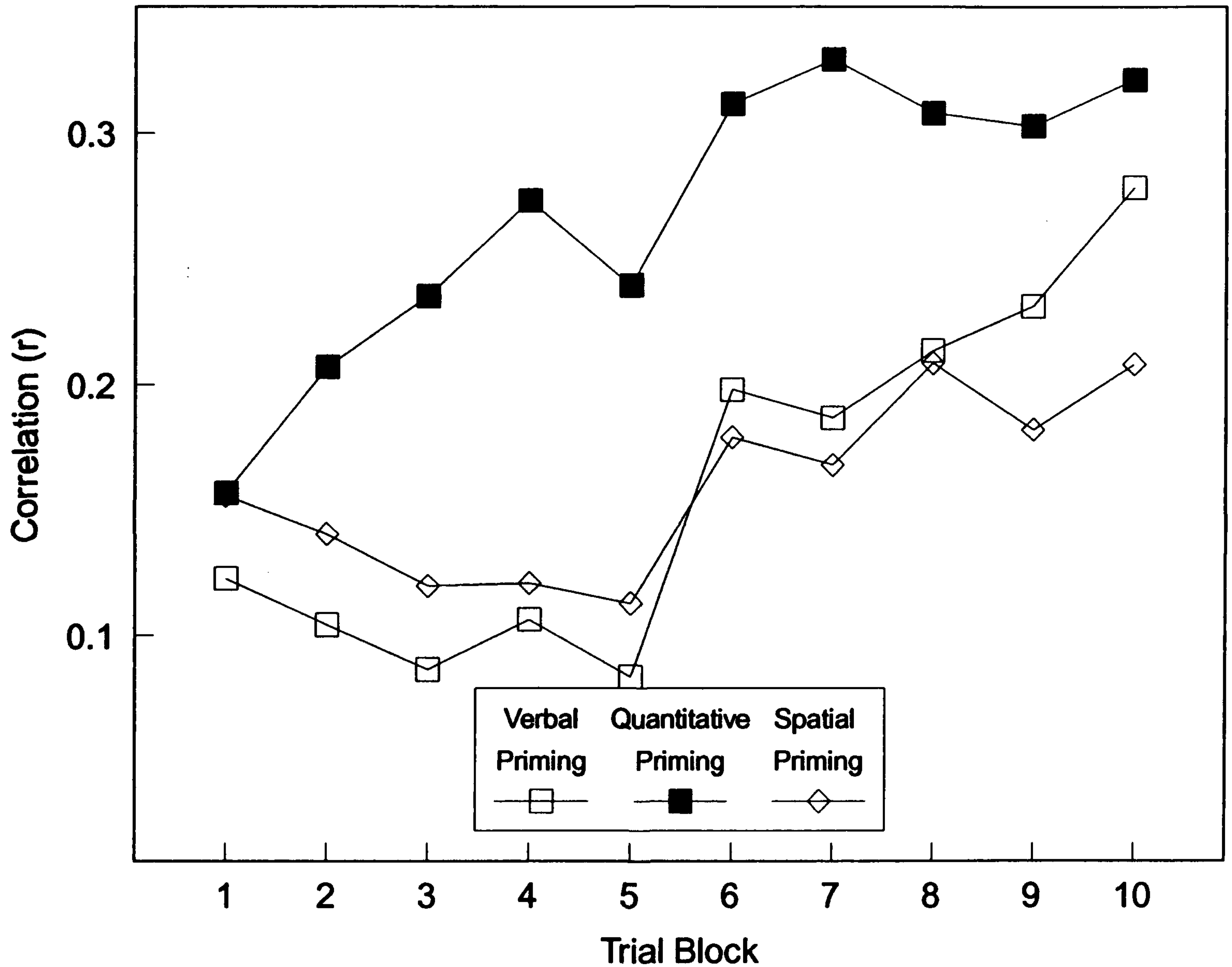

Figure 8: Correlations of Quantitative Skill Task Latency and Priming by Processing Domain and Trial Block

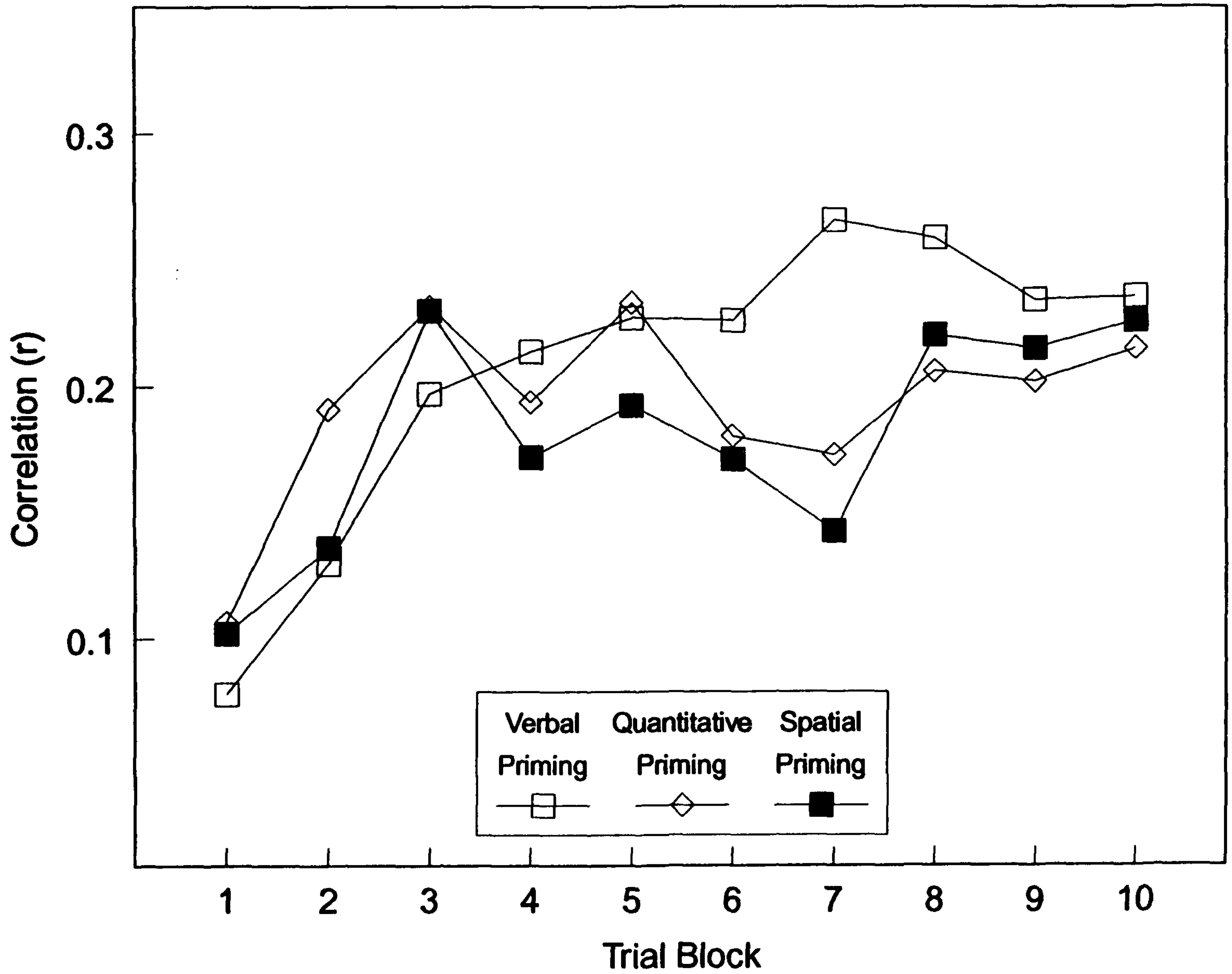

Figure 9: Correlations of Spatial Skill Task Latency and Priming by Processing Domain and Trial Block

First, the tasks used to investigate implicit memory performance in the verbal, quantitative and spatial domains appeared to successfully reflect priming. All three tasks showed substantial mean priming effects that declined systematically with repetition lag. The priming effects were evident in both error and latency savings. Latency savings were the primary focus of the analysis of individual differences. However, error savings were important in demonstrating that latency savings did not simply reflect a shift in the overall error-speed relationship for repeated trials.

Of primary importance, the verbal, quantitative, and spatial repetition priming tasks all displayed moderately high degrees of internal consistency in measuring individual differences. That is, within each task the measurement of priming differences generalized reasonably well across both item content, stimulus match type, and repetition lag. This evidence supported the notion that measurable individual differences in implicit memory phenomena exist.

While some might argue that there will be individual differences in almost anything you attempt to measure, several current cognitive theories postulate the lack of individual differences in automatic and implicit memory processes (Hasher & Zachs, 1979, 1984; Reber, 1989; Reber, et al., 1991). The internally consistent measures of repetition priming reported here contradict such theoretical positions. However, the internal consistency of these measures did not insure that (a) differences measured within specific priming tasks would generalize to those measured by other tasks, and (b) the differences would have the power to explain other, more ecologically meaningful performance differences (e.g., skill learning differences).

Despite the internal consistency of the three priming measures, the relationships among them were modest (correlations ranging from .28 to .38). These relationships in contrast to the reliability estimates suggested a degree of specificity with respect to processing domain or task for differences in repetition priming. However, despite the evidence for specificity, there was also evidence that repetition priming as measured by the three tasks was distinct from episodic recognition ability measured within the same stimulus and processing domains. Priming measures correlated with other priming measures from different processing domains higher than they correlated with recognition measures from different processing domains. Similarly, recognition measures tended to have higher correlations with other recognition measures from different processing domains than they did with priming measures from different processing domains.

Although the intercorrelations of the three priming and three recognition measures suggested a distinction between individual differences in implicit and explicit memory measures, the two constructs were not independent. First, correlations between priming and recognition measures from the same processing domain (and task) were higher than correlations between priming and recognition measures from different processing domains (and tasks). This was especially true for the verbal priming and recognition tasks. Second, an overall composite of the three priming measures had a moderate correlation (r=.43) with an overall composite of the three recognition measures. Thus, while the evidence suggests that the priming and recognition tasks each measured distinguishable abilities, these ability constructs were moderately related.

The finding of a relationship between implicit and explicit measures may appear to be inconsistent with most current views of these memory phenomenon based on previously reported dissociations (see Schacter, 1987). There are at least two possible explanations for this. First, individual differences in domain-specific processing abilities (e.g., spatial versus verbal ability) may drive the relationship between implicit and explicit measures. This is plausible because the relationship between priming and recognition was seen almost exclusively within processing domain and task. This explanation is not necessarily inconsistent with dissociations found between implicit and explicit memory measures using experimental rather than correlational methods.

A second possible explanation for the apparent contradiction of current and prior results regarding the relationship found between implicit and explicit memory measures pertains to task differences. Previous research on implicit memory has primarily used data-driven processing tasks (i.e., tasks that primarily reflect perceptual processing). As a consequence, theories of implicit memory tend to emphasize the perceptual nature of the phenomena (e.g., Schacter, 1990; Tulving & Schacter, 1990). However, as demonstrated by Blaxton (1989), implicit memory measures can be constructed such that conceptually-driven processes are primed. Furthermore, Blaxton's conceptually-driven implicit memory tasks conformed to typical explicit memory tasks with respect to commonly investigated dissociations between implicit and explicit memory (e.g., the effects of elaboration during encoding). Thus, some patterns of dissociation reported in the literature between implicit and explicit measure may be solely a function of the perceptual nature of the implicit memory tasks used.

The priming tasks used in the current research can be best classified as conceptually rather than perceptually driven tasks. As such, they may not be as independent from explicit memory measures for the same events as perceptually demanding implicit memory tasks. Conceptual processes (e.g., word meaning comparisons) tend to be slow compared to perceptual processes, and therefore, they may be much more accessible to conscious recollection. This, however, would not exclude them from being considered implicit memory measures. That is, priming effects in conceptually-driven processing tasks may not depend at all on the conscious recollection of the priming event, even though recollection may be more possible than in data-driven tasks.

The data from the current experiment cannot distinguish between the two explanations offered for explaining the correlations between implicit and explicit measures. However, the data clearly argue for a need for future research on implicit memory to investigate previously observed dissociations in a wider range of processing tasks, especially those that include conceptually-driven processes.

For the purposes of investigating the relationship between differences in repetition priming and differences in skill acquisition, this research first examined the consistency of skill learning differences. As found in the priming task data, measures of skill learning were quite dependable over different items within each of the three tasks. Internal consistency reliability estimates were high for median latency scores after varying amounts of practice and for the parameters of a two-parameter power function fitted to individual subjects' data. Thus, there were measurable individual differences in skill learning. However, as found in the priming data, the measures of skill learning had only modest relationships across processing domains, suggesting a degree of content-specificity in skill acquisition differences.

The patterns of correlation between the implicit and explicit memory measures and skill learning performance were consistent with those previously reported (Woltz, 1988). That is, the only variables that predicted individual differences in skilled performance (i.e., performance in later stages of practice) were the implicit memory measures of repetition priming. This relationship again had a degree of processing domain specificity. Also consistent with earlier findings, early performance was predicted by working memory/reasoning ability. The replication of earlier findings is important in that both constructs were measured in the current research within three different processing domains. This eliminates task-specific relationships as the underlying reason for earlier findings.

Individual differences in the early or declarative stages of skill learning have been relatively easy to account for both empirically and theoretically (see Ackerman, 1988; Cronbach & Snow, 1977; Fleishman, 1972; Fleishman & Hempel, 1954, 1955; Kyllonen & Christal, 1989; Kyllonen & Woltz, 1989). The processes of declarative knowledge acquisition are thought to involve the interaction of working memory and existing declarative knowledge structures (Anderson, 1983; Kyllonen & Christal, 1989). Correspondingly, measures of individual differences in early declarative stages of skill learning have been shown to correlate highest with measures of working memory capacity and prior knowledge (Kyllonen & Woltz, 1989; Shute, 1990, in press; Woltz, 1988). However, individual differences in later stages of skill acquisition have been more elusive to explain. Some have argued that differences in later skill performance are task- and situation-specific and therefore do not correlate with any stable cognitive traits (e.g., Fleishman, 1972). More recently however, Ackerman (1988) has proposed a theory of changing ability correlations with skill development. In this theory, early learning differences are associated with general ability (g), and differences in later learning are associated with perceptual speed and psychomotor abilities. Despite evidence in support of these hypothesized relationships (Ackerman, 1988, 1990), this theory remains limited because it focuses on the role of ability factors rather than specific cognitive processing differences involved in skill acquisition.

The current findings suggest a way to conceptualize specific processing differences that underlie individual differences in later stages of skill learning. As reviewed earlier, some memory theorists have interpreted neurological studies to suggest that procedural and declarative memory systems are independent. Furthermore, repetition priming has been thought to reflect the procedural memory system (Squire, 1986). The proposal of different memory systems is somewhat controversial (e.g., Roediger, 1990), and not entirely supported by the current finding that implicit and explicit measures were correlated. However, this theoretical perspective, as well as correlational data reported here, do suggest the possibility that individual differences in both later stages of skill learning and repetition priming may reflect similar memory mechanisms that differ from those involved in tasks that require more semantic and episodic memory processes, including the early stages skill learning.

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